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Health-Fots- A Latency Aware Fog Based IoT Environment and Efficient Monitoring of Body's Vital Parameters in Smart Health Care Environment

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Abstract

Internet of Things (IoT) integrated with the disruptive technologies are becoming increasingly popular and they have extended their capabilities in all domains such as automotive, health care and automation. IoT is connecting the billions of devices and humans to bring the fruitful advantages to society. Since IoT devices are operated with the centralized cloud environment, pervasive and continuous monitoring of the user information can be facilitated. However, owing to the inherent characteristics of cloud, such as large end-to-end latency, larger bandwidth consumption, handling the larger volume of data from the IoT devices would be bottleneck for implementing the IoT for the smart health care system that aids for the treatment and diagnosis process. To address these issues, this research article proposes powerful paradigm, Heath-FoTs (Fog of things) which incorporates the fog devices where the data are processed and filtered near the IoT nodes which is useful for improving the quality of services. To further improve the speed of communication, distributed fogs are introduced between the IoT devices and Cloud to process the health care data and provides the optimal solution to tackle the latencies problems and bandwidth requirements. The complete experimentation is carried out using the NodeMCU and Raspberry Pi 3 Model in which the MQTT (Message Queuing Telemetry Transportation) protocol is used as the major communication protocol between the IoT and Fog Nodes. To evaluate the proposed model, performance metrics such as latency, throughput, and communication cost is measured and compared with the traditional environments. Results demonstrate the Health-FoTs environment has shown the promising performance with the 23% lesser latency, 32% higher throughputs and 25% less communication overhead than the traditional IoT infrastructure and proves its strong place for the high speed health care environment.

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1. Introduction

The Internet of Things (IoT) represents a structured methodology for establishing global connections between individuals, devices, and services via the Internet. It facilitates seamless interaction and cooperation to enable the gathering, storage, exchange, and monitoring of data [1]. This technology significantly simplifies intricate tasks, reduces manual effort, and saves time in daily activities. IoT integrates various electronic elements, including sensors, microcontrollers, and communication modules [2–5]. These components are capable of collecting data, transmitting it to cloud platforms, and enabling real-time analysis to deliver immediate support and services to users.

One of the significant applications of IoT lies in the development of ambient-assisted living systems, which facilitate health monitoring and support individuals in managing their daily activities. Patients in hospitals, particularly those in Intensive Care Units (ICUs), are often monitored by medical staff; however, human involvement can occasionally lead to unavoidable errors [6].

These IoT device s accurately collects and generates the enormous and exploding data varieties makes the cloud to face the various challenges due to lack of resources in the cloud and increased traffic in the entire network[7,8]. To face the challenges, fog computing has shown the brighter light of deployment in terms of processing the data which is highly sensitive at the network edge near the source devices rather than sending the huge bulk of IoT generated data for cloud processing [9-12].

The emergence of fog computing [13] was driven by specific limitations in traditional computation models. This innovative approach is characterized by its ability to process time-sensitive data efficiently. It ensures real-time data analysis and delivers responses within milliseconds based on predefined policies. Additionally, it transmits only selective data to the cloud, specifically the portions requiring long-term storage or historical evaluation.

To tackle challenges such as high bandwidth demands, geographically distributed networks, ultra-low latency, and privacy-critical applications, a computing paradigm that operates nearer to connected devices is essential. Both academic researchers and industry practitioners [14,15] have introduced the concept of fog computing as a solution to these challenges, offering a framework that brings computational processes closer to the edge of the network.

Fog computing serves as an intermediary layer between cloud systems and IoT devices by providing localized computing, storage, networking, and data handling capabilities at network nodes near IoT devices [16]. This enables processes such as computation, storage, connectivity, decision-making, and data processing to take place along the route from IoT devices to the cloud as the data is transmitted upward.

A. Motivation and Contribution

To achieve the much lower latency and high performance, this research article proposes the Health FoTS – A Fog based health care monitoring system integrated with the IoT data collection systems. Moreover, distributed fogs are introduced in which the Fogs are placed between the IoT devices based on the novel principle of Distance Aware Placement Algorithm (DAPA). The main contribution of the paper is as follows

1. Proposes the Fog Based Health care Monitoring systems-Health-FoTs which integrates the Fogs between the IoT data and Cloud server to achieve the higher performance and least latency.
2. Introduces the distributed fogs which is deployed based on the principle of Distance Aware Placement Algorithm (DAPA) for an efficient capturing of the IoT medical data with an effective utilization of bandwidth and less communication cost.
3. Experimental test –beds are designed based on NodeMCU boards interfaced with the medical sensors and raspberry pi model b+ which acts as distributed fog gateways (DFG) between the NodeMCU triggered IoT devices and Cloud servers. MQTT (Message Queuing Telemetry Transportation) and Thing Speak Cloud is used for communication and monitoring of the data respectively.
4. Evaluation metrics such as latency, communication overhead, bandwidth utilization are measured and compared with the other existing IoT and Fog based healthcare infrastructures. The proposed model has shown the brighter light of the deploying the distributed fogs for an efficient monitoring the health care data.

1.2 Organization of the Paper

The research article is structured as follows as: **Section-2** presents the related works by more than one authors. **Section-3** presents the complete system model used for the experimentation. The proposed methodology with its detailed description is presented in **Section-4**. The experimental analysis, results discussions are presented in **Section-5**.Finally the paper is concluded with the future enhancement in **Section-6.**

2. Related Works

Quy et al. (2021) [17] compared cloud, edge, and fog computing technologies to address high service response times in emergency healthcare scenarios. They proposed a framework for Fog-IoHT applications, which aims to reduce latency and improve emergency response times. The framework demonstrated significant potential in enhancing healthcare service delivery. However, integrating fog computing into IoT healthcare applications presents challenges, such as complex data management, real-time processing, and maintaining consistency across diverse healthcare environments. The study highlights that while fog computing offers improvements, there are still issues related to the practical implementation and integration with existing systems.

Kashyap et al. (2022) [18] provided a comprehensive survey on fog and IoT-driven healthcare, focusing on various technologies, techniques, and performance parameters. They emphasized the benefits of fog computing in reducing latency, improving storage capacity, and enhancing scalability. The survey also noted challenges, including the complexity of implementing fog computing in real-world scenarios and ensuring scalability. Issues such as integrating fog computing with existing healthcare systems and managing diverse data sources were highlighted as areas requiring further research. The survey effectively outlines the current state of the field but also underscores the need for continued development to address these challenges.

Kumari and Jain (2022) [19] proposed a fog-based healthcare monitoring system within SDN-IoT networks. Their system used three sensing devices to collect health data, which was analyzed using a novel fog computing interface. The study highlighted improvements in cost, power usage, and latency compared to traditional systems. Despite these advantages, the system faced drawbacks related to high power consumption and ensuring real-time data accuracy. The challenges included managing the computational load and ensuring the system's performance under varying conditions. The integration of fog computing with SDN-IoT networks also posed difficulties in balancing performance and resource utilization.

Elhadad et al. (2022) [20] developed a healthcare monitoring framework utilizing fog computing for real-time notifications. The system monitored various patient metrics, including body temperature, heart rate, and blood pressure, and provided real-time alerts to caregivers. Machine learning algorithms were employed to enhance the accuracy of notifications. However, the framework encountered issues with real-time processing, especially in complex scenarios, and faced challenges in maintaining consistent performance across different environments. Ensuring reliable and timely notifications remained a critical concern, highlighting the need for further optimization of the system.

Mala et al. (2022) [21] introduced an IoT-enabled smart healthcare system leveraging fog computing and deep learning for detecting heart-related issues. The system utilized the Healthfog concept to analyze data from IoT devices, providing real-time heart disease diagnosis. Although the system demonstrated effectiveness in early detection, it faced challenges related to power consumption, accuracy, and managing large data volumes in real-time. The integration of deep learning with fog computing required significant computational resources, which could impact system efficiency and scalability in practical applications.

Ahmad et al. (2023) [22] proposed an IoT-fog-based healthcare system incorporating blockchain technology for enhanced security and privacy. Their system used critical and non-critical fog clusters to manage patient data, with blockchain ensuring privacy protection. While the approach effectively reduced response times and safeguarded patient records, it also presented challenges in integrating blockchain with existing healthcare IoT ecosystems. The system needed to address issues related to data management, performance under heavy data loads, and maintaining a seamless user experience.

Tripathy et al. (2023) [23] developed an intelligent healthcare system on a fog platform, utilizing quartet deep learning and edge computing. Their approach aimed to optimize performance and reduce latency by integrating fog services with IoT devices. The system showed improvements in managing health data and resource usage. However, it faced limitations in balancing precision and response time, which are critical for real-time healthcare applications. Ensuring that the system met the diverse needs of users while maintaining high performance remained a significant challenge.

Navakauskas and Kazlauskas (**2023) [24]** conducted a systematic review of fog computing in healthcare, analyzing recent trends and benefits. They focused on how fog computing addresses issues like high response latency and large data volumes. The review highlighted the promise of fog computing in improving healthcare data management through real-time analytics and AI. Nonetheless, it also pointed out ongoing challenges, such as the maturity of fog computing solutions, integration with existing systems, and effectively handling big data. The study emphasized the need for continued research to address these challenges.

3. System Model

The system model considered for IoT topology is shown in Figure 1. The model consist of multiple IoT devices connected to a Fog gateway. Each device can communicate with the other devices only through the gateways using wireless technologies such as WIFI [25]. The IoT devices involved in this model are small-size, memory and energy constraint devices. NodeMCU devices interfaced with Temperature sensors (T), Blood Pressure sensor (BP) act as the IoT nodes whereas raspberry pi model b+ act as the Fog gateways. A MQTT protocol is used for communication between the NodeMCU, Raspberry Pi Model B+ and Cloud server.

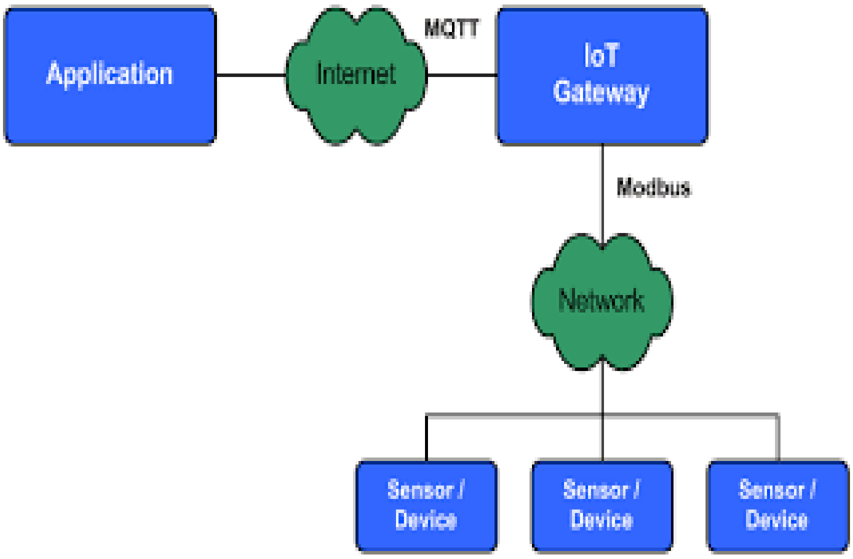


Figure 1. IoT and Gateway System Model Used in the proposed research

4. Proposed Methodology

The complete system architecture is shown in Figure 2. In the figure 2, five different IoT sensors exchange the medical data with a fog layers that allows for communicating them with the cloud servers. The detailed description of the proposed architecture is explained as follows

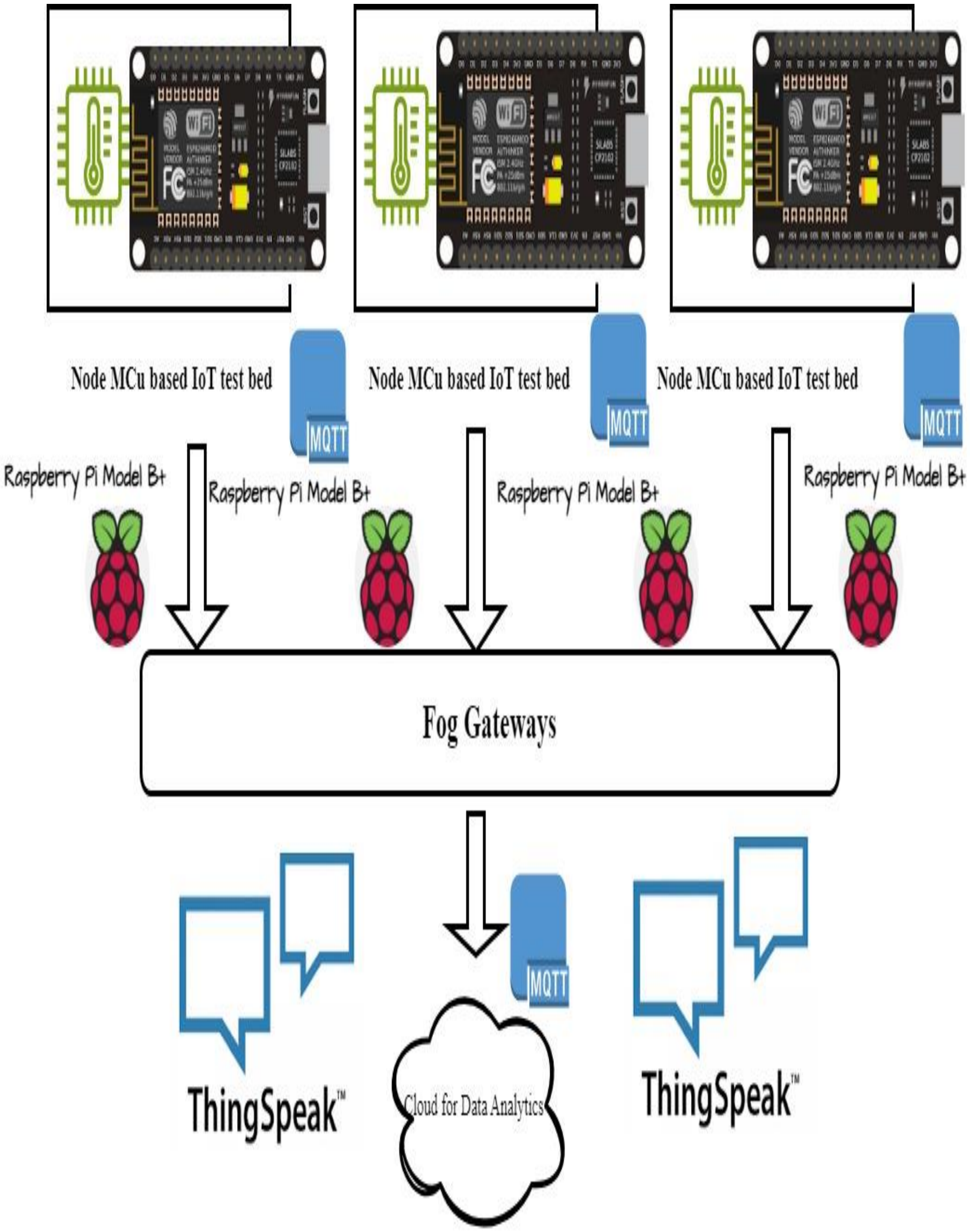


Figure 2. Proposed Block framework for the Fog - IoT Health Care Devices

A. **Sensor Network Layer**: Bio-medical Sensors such as temperature sensors, blood pressure sensors, and pulse rate are used in the experimentation. All the sensors are interfaced with the NodeMCU microcontrollers and then transmitted to the fog computing devices through the WIFI network. . As discussed, to collect the medical data, IoT systems with 8-BIT NODEMCU as main processing unit interfaced with the 10-BIT SPI (Serial peripheral Interfaces) based MCP3008 Analog-to-Digital Convertor (ADC) and ESP8266 WIFI transceivers. All sensors connected to these boards gather medical data from subjects and upload it to the Thing Speak cloud for additional analysis [29]. The IoT boards are powered by 3.3V batteries, which can be replaced with alternative batteries once they are depleted. Table 1 illustrates the specification of the sensors and controllers used in the IoT layers.

Table 1: Hardware Specifications used in the IoT layers

Sl.No	Hardware Details	Description
1	Number of Sensors in each sensors	05
2	Number of IoT test beds used	05
3	Temperature sensors	05
4	Blood pressure sensor	05
5	Communication used	WIFI
6	Analog-to-Digital Convertor	10-bit MCP3008 ADC

B. Fog Layer: Fog layers consists of several distributed nodes placed near the IoT nodes. These fog node are called as fog gateways. These gateways are used for facilitating the storage, computing and network connections that is distributed near the sensors. The distribution of the fogs near the IoT nodes are responsible for the data reception, analysis of the fog nodes and finally storing all these data in the cloud. The placements of fog gateways are based on the distance aware placement algorithm (DAPA). The detailed description of the algorithm is as follows

a.) DAPA in Fog Layers

The proposed DAPA model works on the principle of received signal strength measurement on the on-board units. The proposed algorithms measures the RSSI in which then measures the distance between the IoT nodes and Fog gateways. The mathematical expression for calculating the RSSI and distance is given as follows

$$RSSI = P(t) - P(D) \qquad (1)$$

Where P(t) is Power Transmission P(D) – Path loss in Distance D where D is measured as

$$D_{(N_s,BS)} = 10\left[\frac{(P_o - F_m - P_r - 10n\,log(f) + 30n - 32.44)}{10n}\right] \qquad (2)$$

Where P_o is the power of the signal (dBm) in the zero distance, P_r is the Signal power (dBm) in the distance d, f is the signal frequency in MHz, F_m is the Fade margin and n is the path-loss exponent.[26]

The network parameters that are measured act as the initially before the placement of fog nodes Experimentally,RSSI values can be calculated using AT(Attention commands) of transceivers interfaced with microcontroller of IoT devices. DAPA enhances existing methods by strategically placing fog nodes closer to data sources based on distance metrics, thereby reducing latency and improving data processing efficiency. Unlike traditional placement strategies, DAPA ensures optimized resource utilization and faster response times, making it particularly effective for real-time healthcare IoT applications. Table 2 illustrates the different network parameters used for measuring the distances.

Table 2: Different RSSI parameters obtained experimentally in the IoT devices

Sl.no	RSSI (dbm)	Distance between the IoT devices and Gateways (meters)
1	-95 to -83	5
2	-87 to -77	4
3	-78 to -71	2.5

After calculating the network parameters, fog nodes are placed at the position near to the IoT nodes where the signal strength is higher. **Algorithm-1** presents the complete procedure for the DAPA model in determining the distance between the nodes and fog gateways.

```
Steps   Algorithm-1 // Pseudo-Code for the DAPA in Fog layers
1       Input  :   RSSI, Distance Measurements
2       Output  :  Distributed Fogs
3       Start :
3       Measure the RSSI and Distance using Equation(1) and(2)
4       If (RSSI > Threshold (By thumb Rule) && Distance< Thersold)
5               Shortest Distance detected
6                   Distribute the Fogs near the IoT Nodes
7       End
```

After placing the fogs near the IoT nodes, medical data are then processed and transmitted to the cloud for determining the emergency data.

C. Cloud Layers

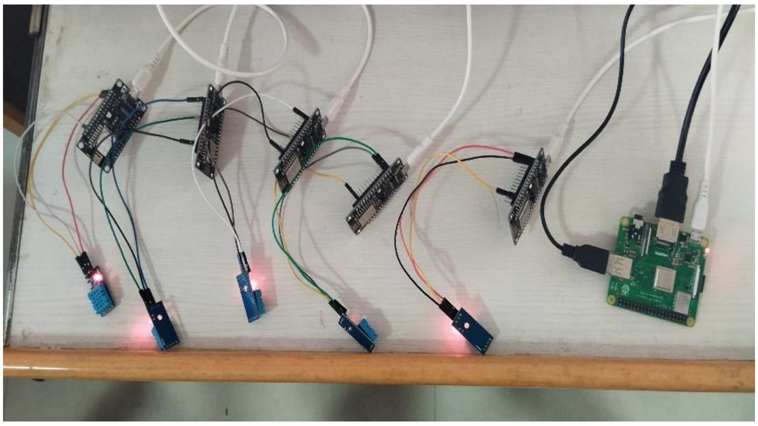
The cloud layer encompasses a network of distributed resources, data repositories, and servers. The cloud manager oversees all devices linked to this layer, enabling efficient reception, processing, and storage of patient information. This data is instrumental in evaluating both the patient's historical health records and their present condition. The proposed study highlights the benefits of utilizing cloud layers, such as facilitating the processing of data from fog layers while offering expanded storage capacity to retain healthcare information for future diagnostics and therapeutic applications.

D. MQTT –Communication Protocol

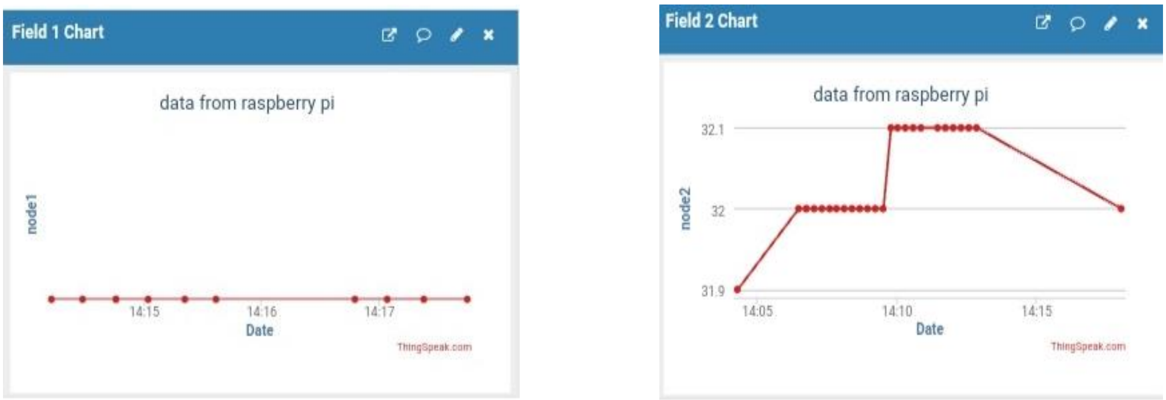
MQTT [26] serves as a lightweight messaging protocol designed to facilitate message exchange across a wide range of devices, such as sensors, actuators, mobile phones, embedded systems, and laptops, even in environments with limited resources or significant latency. This protocol employs a publish/subscribe communication model tailored for such networks. The study leverages the Mosquitto library to implement MQTT-based data transmission, enabling efficient communication from IoT nodes to fog layers and subsequently to the cloud.

5. Implementation Details

The complete health care infrastructure was developed and deployed in the experimentation test bed consist of the NodeMCU and Rasberry Pi Model B+ as fog gateways. Embedded C and Python programming is used for deploying the complete infrastructure for the IoT-Fog based healthcare systems.



(a)



(b) (c)

Figure 3. a) Hardware Test Bed with NodeMCU as IoT board with the Raspberry Pi Model B+ as Fog Gateways b)&c) Cloud data stored in the ThingSpeak from Fog gateways

Distance	RSSI
2	-30
3	-42
5	-68
8	-72
9	-97

(a) (b)

Figure 4. a) Mobile Application developed for monitoring the IoT sensor values b) Mobile App developed for RSSI Measurement to deploy the DAPA model.

Figure 3 shows the experimental test beds using the NodeMCU boards and Raspberry Pi Model B+ as Fog gateways. For an effective experimentation, 5 nodes interfaced with the temperature sensors ad blood pressure sensors. Figure 4(c-d) shows the sensor data collected from the cloud from the fog gateways which are stored in the cloud for further processing. To monitor the RSSI and Sensor data in the fog gateways which are collected from the IoT nodes, Mobile App was developed using Flutter which shown in Figure 4(a-b)

6. Results and Discussion

The various performance metrics such as latency, communication overhead, and bandwidth utilization are measured and compared with the traditional IoT structure and proposed Fog structures. The proposed system achieved a **32% reduction in latency** compared to traditional cloud-based IoT setups, ensuring near real-time monitoring of vital parameters. Reduced latency ensures faster data transmission, critical for real-time patient monitoring. Improved throughput supports the handling of large volumes of medical data efficiently, while lower computational overhead optimizes resource utilization, making the system more suitable for resource-constrained IoT devices in healthcare environments. These improvements collectively enhance the performance and reliability of secure healthcare IoT networks. The proposed fog-based setup is inherently scalable, designed to support large-scale healthcare applications by efficiently distributing computational tasks across multiple fog nodes. This architecture reduces central server dependency, ensuring low latency and high performance, even as the number of connected devices and data volume grows.

a.) Latency Analysis

Latency is measured as the time taken by the data from the source to destination. To prove the superiority of the fog based proposed model, three existing models has been considered. IoT-Model-1[27] details about the traditional IoT model without any fog gateways. In the IoT-Model-2[28] describes about the IoT with Fog gateways in which the placing of fogs is based on the principle of randomized principle and IoT-Model-3 details the IoT with the fog placements using Greedy method [30]. In this research, latency is requested time delay (T(D)), processing time delay(P(D)), queuing time delay((Q(D)) and propagation delay(Pr(D)). Mathematically the latency in the fogs is calculated as given in Equation (3)

$$D(Fogs) = T(D) + P(D) + Q(D) + \Pr(D) \qquad (3)$$

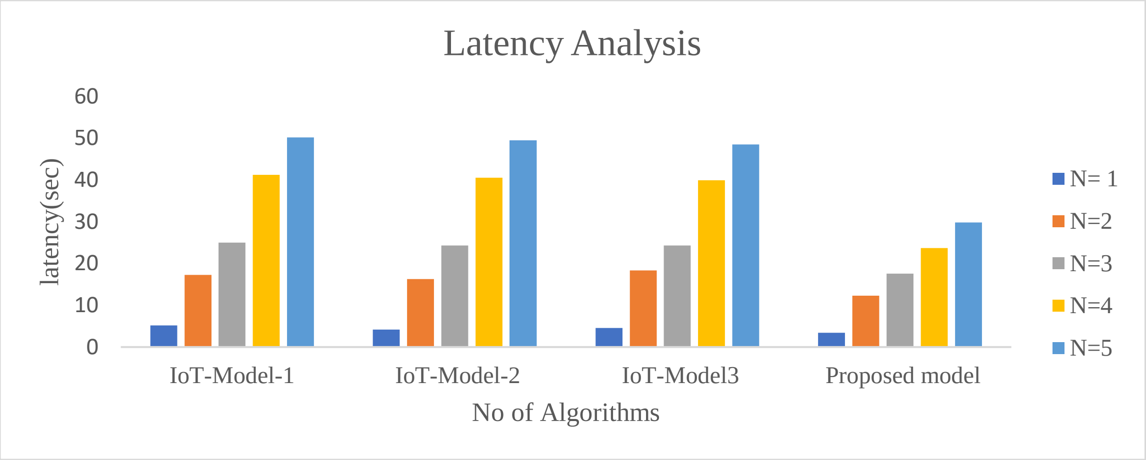


Figure 5. Latency Analysis for the Different models deployed for the experimentation process (For N=number of IoT nodes interfaced with the medical sensors)

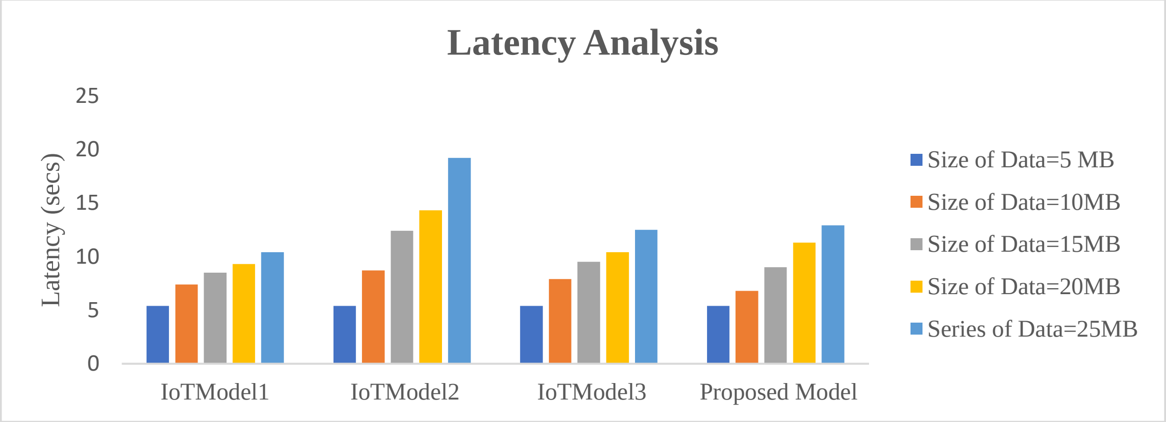


Figure 6. Latency Analysis for the Different models deployed for Different size of data transmission (For N=number of IoT nodes interfaced with the medical sensors)

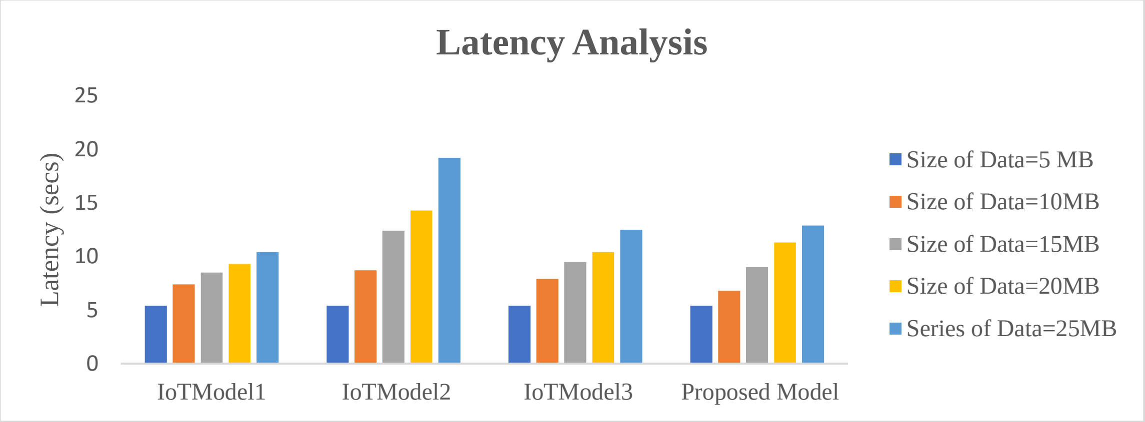


Figure 7. Latency Analysis for the Different models deployed for Different size of data transmission

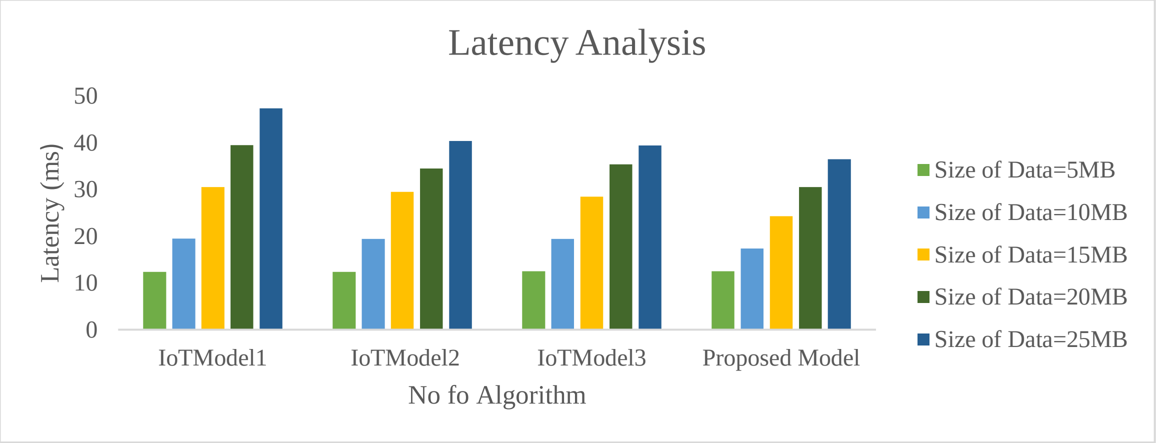


Figure 8. Latency Analysis for the Different models deployed for Different size of data transmission

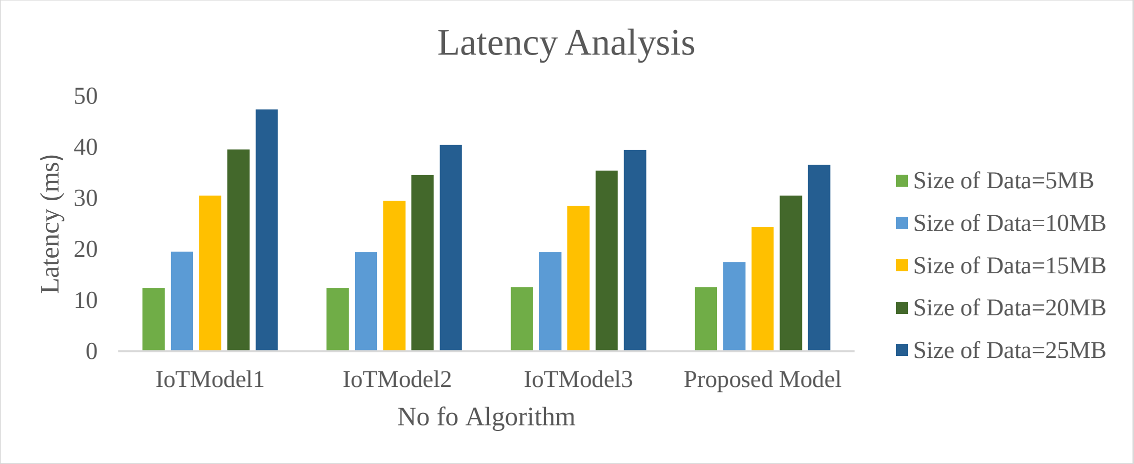


Figure 9. Latency Analysis for the Different models deployed for Different size of data transmission

7. Discussions

Figure 5 shows the latency of different IoT environments and proposed Fog model. In Figure, latency of 5 nodes and two medical sensors deploying the IoT- Model1 consumes 5 to 50 secs as the number of nodes increases in the network. In the similar fashion, IoT-Model2 and IoT- Model3 consumes from 5 to 39secs and 5 to 29.5secs as the number of networked nodes increases. But the Fog based proposed model consumes from 5 to 19.5secs as the number of nodes increases. It is very clear that latency is reduced to 50% than model-1, 39% less than model-2 and 21% less than model-3. The proposed fog based model has consumed less time. Figure 6-9 shows the latency of different networks by the transmission of variable data size. As shown in Figure 6 , latency increases linearly as the size of the data s and no of nodes increases As the data size increases, latency of first three existing models increases from 5 to 20.2 secs for node -1 and node-2 , 5 to 38.5secs for node-3,4,5 respectively. But the Fog based proposed model suffers from latency ranges from 5.4 to 12.5 secs for one nodes and 5 to 32.3secs for five nodes. Hence it is clear that the latency of the proposed model is 50% less than other models for one node deployment and 25% less for the five nodes when the datasets increases. From the experimentation figures, it is very clear that proposed Fog based Model has less latency than the other existing models.

Throughput Analysis

Throughput is ratio between the amounts of data transmitted from the source to the data received at the destination.

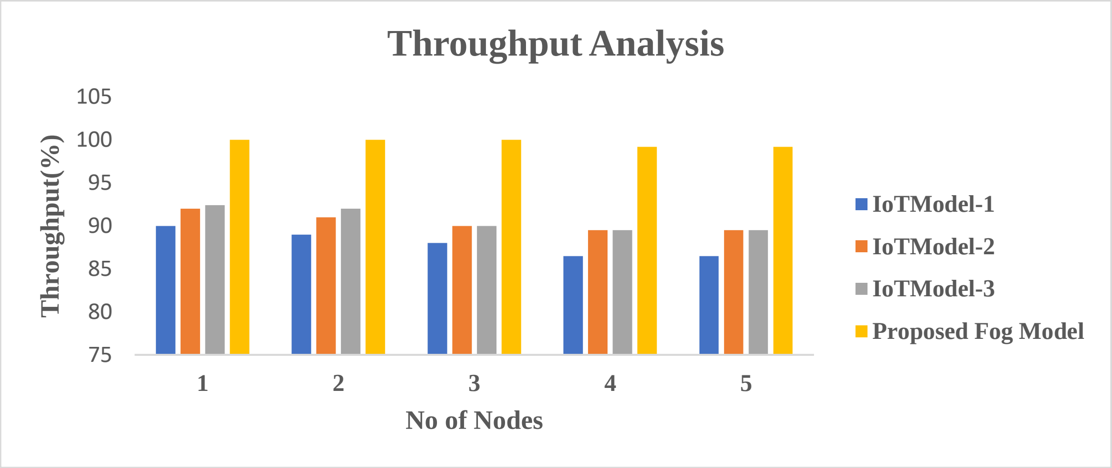


Figure 10. Throughput Analysis of the Different Models in transmitting the medical data sensors

Discussion (A)

Figure10 shows the throughput of the various IoT models and Fog models has been demonstrated. From the Figure, it is clear that throughput of the proposed model has maintained the throughput from 100% to 99% as the data size increases whereas the other models throughput degrades from 100% to 88% as there data increases. From the Figure 10, it is clear that the proposed fog model has more throughput than the other models.

Computational Overhead

The computational overhead (CO) is calculated based on the running time of the algorithm on each and every fog gateway. Table 3 presents the computational overhead for the different models in the experimental test beds.

Table 3: Computational Overhead for the Different Fog Based IoT Devices

Data Size	Computational Overhead (secs)			
	IoT-Model-1	IoT-Model-2	IoT-Model-3	Proposed Model
5MB	4.2	3.9	3.5	2.8
10MB	7.5	5.8	5.4	3.6
15MB	10.2	9.2	9.1	5.9
20MB	15.9	13.6	13.5	8.2
25MB	21.9	19.4	19.2	11.5

Discussion (B)

Table 3 presents the computational overhead for the different fog based IoT environment. From the table 3, it is evident the proposed model has consumed only 11.5secs for running the 25MB data which is 30% and 50 % less than the existing IoT models. As the data size increases, proposed DAPA based fog model has lesser computational overhead than the other models which is illustrated strongly in Table 3.

8. Conclusion and Future Direction

This research paper proposed a fog based IoT framework for the healthcare data with the novel DAPA distribution of fogs nodes. For an effective transmission of the medical data, distance aware placement algorithm is deployed for the fog nodes near the IoT nodes. The extensive experimentation is carried out using the real time test beds designed based on the NodeMCU and Raspberry Model B+ with MQTT protocol as the major communication media. Computational Overhead, Latency and throughput are calculated and measured with the existing models. Future research directions, including testing alternative communication protocols like CoAP or AMQP to optimize data transmission and exploring lightweight security solutions tailored for resource-constrained healthcare IoT devices. These advancements aim to further enhance the reliability and efficiency of IoT-based healthcare systems. Results demonstrates the proposed model has shown 50% faster than the existing models and produces 99% throughput in transmitting the medical data. The DAPA based distributed Fogs proves its strength in handling the medical data with the less latency and high performance.

As the future direction, light weight security framework is needs brighter light to ensure the security of data against the growing multiple attacks. The implementation of secured fogs in the proposed framework will increase the higher mitigation performance against the eavesdropping attacks.

Data Availability

The data used to support the findings of this study, which includes a newly created dataset, is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Ethical Approval

This article does not contain any studies involving human participants or animals conducted by the author.

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