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Intelligent Load Balancing Framework for Optimal Resource Utilization in Fog-enabled IoMT Environment

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Abstract

The rapid adoption of Internet of Things (IoT) technologies in healthcare has given rise to the Internet of Medical Things (IoMT), which has transformed patient care and medical services. The IoMT, when combined with Fog Computing, provides a powerful paradigm for processing and analyzing healthcare data at the network edge. This paper proposes an innovative intelligent load balancing framework designed specifically for fog-enabled IoMT environments for optimizing resource utilization, improving system performance, and ensuring timely and efficient healthcare service delivery. The framework dynamically distributes computing tasks among fog nodes based on re-al-time parameters such as node capacity, latency, and workload. By combining ma-chine learning (ML) models and data analytics, the system adapts to changing patterns in medical data, ensuring adaptive load distribution and faster response times. The proposed framework addresses the unique challenges facing healthcare applications, such as low latency and energy consumption in data transmission.

Keywords

Internet of Medical Things, Fog Computing, Machine Learning, Load Balancing, Healthcare, Quality of Service, Security and Privacy

1. Introduction

The convergence of Internet of Things (IoT) technologies and the healthcare domain has resulted in the evolution of the Inter-net of Medical Things (IoMT), a transformative paradigm with enormous potential for improving patient care and optimizing medical services [1]. IoMT refers to a vast ecosystem of interconnected medical devices, wearables, and sensors that produce unprecedented amounts of real-time healthcare data. Healthcare providers can use the power of IoMT to remotely monitor patients, facilitate timely interventions, and gain valuable insights for personalized treatment strategies [2]. However, the sheer volume of data generated by IoMT devices creates challenges for processing, analysis, and real-time decision-making, necessitating advanced computational frameworks. Fog Computing has introduced a decentralized approach to processing IoT data by moving computing resources closer to the network edge. In the context of IoMT, fog computing offers a valuable solu-tion to the latency-sensitive and resource-intensive nature of healthcare applications. This paper addresses the critical issue of load balancing in fog-enabled IoMT environments, where efficient use of computational resources is critical for providing seamless healthcare services [3]. As medical applications become more reliant on timely data processing at the edge, a sophis-ticated intelligent load balancing framework is required to ensure optimal performance, scalability, and resilience in the changing healthcare workloads [4].

The IoMT landscape presents unique challenges, such as the need for low-latency processing, strict privacy requirements, and reliable connectivity. Traditional cloud-based solutions may not be sufficient due to latency issues and the risk of data breaches. As a result, this paper aims to contribute to the emerging field of fog-enabled IoMT by proposing an intelligent load balancing framework that uses cutting-edge algorithms, machine learning models, and adaptive strategies to dynamically distribute computing tasks among fog nodes. This framework aims to improve the efficiency of healthcare data processing at the edge, laying the groundwork for responsive and secure IoMT solutions. The growing integration of medical devices, wearables, and sensors in IoMT scenarios emphasizes the importance of developing intelligent frameworks capable of dealing with the dynamic nature of healthcare data. This paper aims to introduce a comprehensive solution that not only optimizes load balancing in fog-enabled IoMT but also addresses the changing demands of healthcare applications by exploring existing challenges and analyzing current research gaps. The proposed framework aims to propel the IoMT ecosystem into a new era of efficiency, re-sponsiveness, and better patient outcomes by increasing the intelligence of load balancing mechanisms.

The growing importance and inherent challenges of smart healthcare applications motivate this research work. The need for effective load balancing grows as healthcare services depend increasingly on real-time data processing, remote patient moni-toring, and timely decision support systems. Conventional cloud-based load-balancing approaches unable to satisfy the unique demands of the healthcare industry, where low latency and resource optimization are essential. It aims to optimize the alloca-tion of resources and improve the overall quality of healthcare services. The motivation extends to the dynamic nature of healthcare workloads, which have varied demand patterns and a critical need for low-latency responses. This research aims to advance Fog-enabled IoMT systems by addressing these challenges using an intelligent load balancing framework, thereby im-proving the efficiency and reliability.

The rest of the paper is organized as follows. Section-2 discusses the background in the proposed work, which covers the evo-lutions of IoMT, fog computing and load balancing. The Section-3 covers the literature review that delves into existing research for load balancing in healthcare applications using fog computing to find the research gaps. In Section-4, proposed a solution for dynamic resource allocation at fog layer to balance the load which in turns optimize the latency, energy consumption etc. The experimental results to measure the performance of the proposed framework are discussed in Section-5. The Section-6 discusses the challenges and future research directions for further investigation in the field of fog-enabled IoMT. Finally, the Section-7 is concluding the paper by summarizing key findings and contributions and emphasizing the importance of load bal-ancing framework in healthcare systems.

2. Background

The IoMT has caused a paradigm shift in the foundation of modern healthcare, paving the way for more interconnected, intelligent, and data-driven healthcare systems. The IoMT represents the integration of medical devices, wearables, and sensors connected to the internet, allowing for the seamless collection, transmission, and analysis of health-related data. This interconnected ecosystem enables real-time monitoring, diagnosis, and personalized treatment strategies, with the potential to significantly improve patient care and overall healthcare efficiency.

2.1. Evolution of Healthcare X.0

The development of healthcare systems is closely linked to the advancement of medicine. In the beginning, when medicine was still mostly practiced by skilled physicians using natural remedies like herbs, it was known as Medicine 1.0 and Healthcare 1.0. To address significant health issues, this era concentrated on clever public health strategies. Then, with the development of revolutionary discoveries like antibiotics and the use of X-rays, came Medicine 2.0 and Healthcare 2.0, which sparked the growth of big hospitals and specialized diagnostic methods. Mass production in medicine and industrialization were the defining features of this era.

Surgery was transformed by developments in electronics and microtechnology, resulting in the creation of Medicine 3.0 and Healthcare 3.0. This phase was marked by the use of surgical robots, evidence-based medicine, and sophisticated imaging methods. We are now approaching the era of "Medicine 4.0," or "smart-health." Microelectronics and smart devices are improving healthcare services and quality through the integration of information systems and technologies. A few examples include intelligent implants, telematic therapy, and personalized chemotherapy.

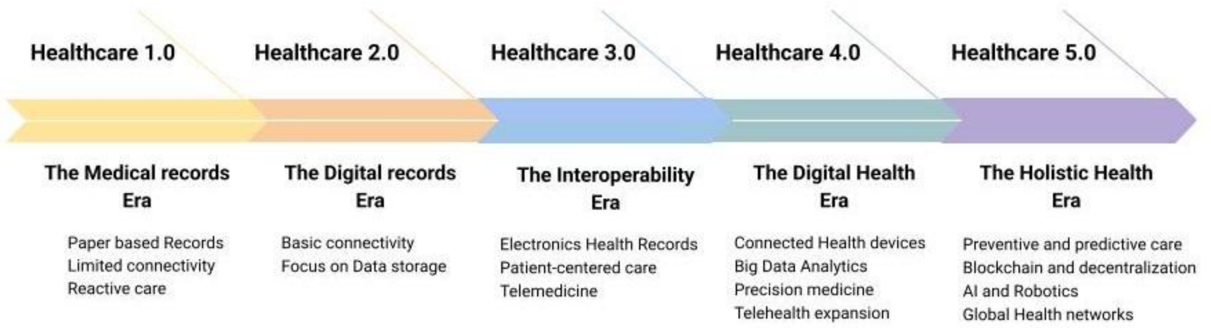

Figure 1. Evolution of Healthcare X.0 [6]

However, despite these developments, problems still exist, particularly with communication. IoT devices and artificial intelligence in healthcare face challenges related to data transmission rate, security, and dependability. The advent of advanced communication technologies such as 5G has ushered in a new era in healthcare, known as Medicine 5.0. This stage prioritizes digital wellness, individual wellbeing over patient wellbeing, and personalization through customer models. In conclusion, the development of medicine and healthcare systems has been characterized by innovation, difficulties, and an increasing emphasis on the well-being of the individual. This has been the case from the early days of herbal remedies to the present era of personalized healthcare [5]. Figure 1 shows the evolution from healthcare 1.0 to healthcare 5.0.

2.2. Fog Computing

Along with the evolution of IoMT, fog computing has emerged as a critical technology in reshaping the landscape of healthcare services. Fog computing expands the capabilities of traditional cloud computing by moving computational resources closer to the network's edge [7]. This decentralized approach reduces latency, maximizes bandwidth utilization, and improves real-time processing capabilities. In the context of healthcare, fog computing is especially useful for handling the massive amounts of data generated by IoMT devices, allowing for faster and more efficient data processing at the edge. Figure 2 shows the basic IoT-based fog computing architecture.

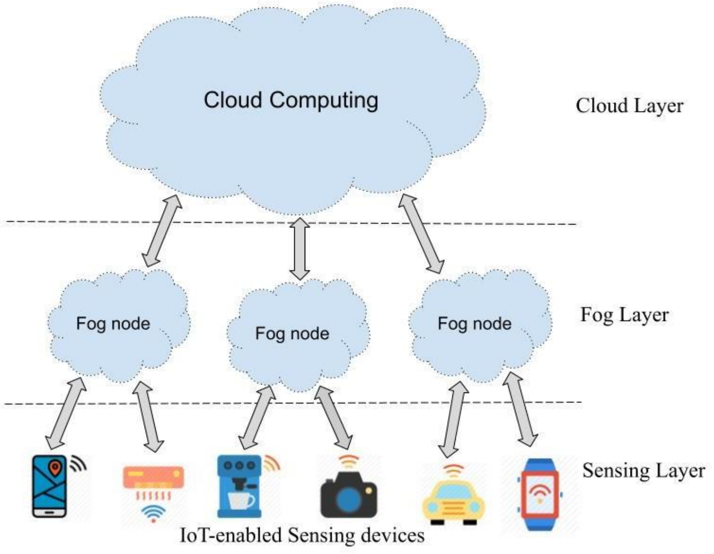

Figure 2. IoT-based fog computing architecture [8]

The sensing layer collect the data generated by the different sensors and transmit to fog layer. The fog layer consists of fog nodes, which process the data and after processing send the data and the processing decision to the cloud layer for further actions and long tern storage. The data from the cloud layer can be accessed at any time to make decisions or further analysis.

2.3 Load Balancing

Load balancing is critical for optimizing the performance and resource utilization of distributed systems, and it is especially important in the context of fog-enabled IoMT. Load balancing is the even distribution of computational tasks across network nodes in order to avoid bottlenecks, maximize resource utilization, and improve overall system responsiveness. Various load balancing techniques have been developed, including static algorithms as well as dynamic and adaptive approaches. These techniques aim to intelligently allocate tasks by taking into account node capacity, workload, and latency. Efficient load balancing in fog-enabled IoMT is critical for dealing with the dynamic and resource-constrained nature of healthcare applications, as well as ensuring timely and accurate medical data processing for better patient outcomes.

3. Literature Review

In this literature review, we provide a thorough examination of recent research attempts to obtain insight into the fog computing landscape. By looking into a variety of studies, we intend to through light on the methodology, approaches, and breakthroughs made in the field of fog computing and IoMT. This extensive research provides us with a detailed understanding of existing state-of-the-art information and techniques employed for load balancing at the fog layer. There is a need of investigation to uncover research gaps, obstacles, and developing trends in the proposed domain. It will eventually guide the creation of our own proposed framework for strengthening load balancing capabilities at the fog layer.

Ijaz et al. [9] has implemented the tri-FogHealth architecture monitors user health through wearable physiological parameters, addressing issues such as latency, data duplication, and fog overloading. It employs quantum neural networks for fault diagnosis and prediction, but has limitations such as user mobility, cloud data transfer, and Bayesian classifier complexity. Manogaran et al. [10] proposed a cost-effective IoT-Fog-Cloud architecture resource allocation scheme that employs iFogSim to reduce node overload, delay, and resource constraints. Regardless of scalability and infrastructure considerations, the scheme ensures node availability, processing, and success ratio.

Asghar et al. [7] describes a fog computing-based health monitoring system employs intermediate layer fog nodes and a load balancing scheme to reduce latency and network usage. This improves system performance by balancing the data transmission load. Future research will look at different load balancing schemes in fog computing architectures for healthcare data processing. Shanshoola et al. [11] has done task scheduling in the fog layer of IoT architecture, proposing a two-stage approach to task scheduling in fog computing. The proposed task classification-based approach for IoT task scheduling in fog computing is efficient and outperforms other scheduling schemes.

Kadam et al. [12] implemented a fog-based asthma monitoring system that responds quickly to client devices while minimizing latency by connecting sensors to fog nodes. It provides reduced network usage, increased efficiency, better healthcare, cost effectiveness, and adaptive monitoring. Challenges include reducing energy consumption in nodes, developing intelligent systems for predicting asthmatic emergencies, and conducting large-scale testing. Stephen et al. [13] has done fault detection and repair using the "cfots networks with ensemble learning" method, which has proven to be more productive than other methods in industrial settings. The method detects and repairs faults efficiently, with a 99.11\% recall and 98.5\% precision. However, the number of sensors in the study limits its scope, and wearable sensor comfort must be considered.

Table 1. Literature Review

Author	**Year**	**Methodology**	**Pros**	**Cons/Future Scope**
Ijaz et al. [9]	2020	Uses wearable physiological parameters and quantum neural networks for fault diagnosis and prediction	Minimizes latency, improves data analysis accuracy, allows offloading procedures when overloaded	Limited to static user mobility, requires some degree of data transfer to the cloud, implementation of Bayesian classifiers increases system complexity and lowers accuracy
Manogaran et al. [10]	2021	Cost-effective resource allocation scheme utilizing iFogSim	Scalability, increased efficiency, optimal resource allocation, non-overloading nodes	Large-scale infrastructure, efficient scheme for various applications with delay and cost being critical factors

Asghar et al. [7]	2021	Load Balancing Scheme (LBS) to reduce latency and network usage	Enhances system performance by balancing data transmission load among fog nodes	Explore and evaluate the performance of various load balancing schemes in fog computing architectures
Shanshoola et al. [11]	2022	Task classification-based approach for IoT task scheduling in fog computing	Superior performance in metrics like ET, FT, and WT of significant tasks	Resource based tasks allocation for best performance
Kadam et al. [12]	2023	Fog-enabled asthma monitoring system utilizing fog nodes to minimize latency	Reduced network usage, Increased efficiency, Cost-effectiveness, Adaptive Monitoring	Reduce energy consumption nodes, develop intelligent systems for predicting asthmatic emergencies, testing on a large scale
Stephen et al. [13]	2023	Method for detecting and repairing faults in industrial settings	Efficient recall and precision in fault detection and repair	Limited number of sensors, Wearable sensors should not cause discomfort
Bai et al. [14]	2023	Aims to ensure privacy and secure data sharing using the Paillier cryptosystem	Low computational costs, Improved efficiency, Equitable cost sharing, User privacy protection	Coarse-grained aggregation, designed for fog-enhanced IoT and may not apply to other contexts
Zuo et al. [15]	2023	Security Intelligent Resource Allocation (SIRA) method using deep reinforcement learning	Efficient resource allocation, Real-time adaptation, Fast Convergence, High performance	Limited application scope, Computational complexity, Resource constraints, Limited evaluation scenarios
Singh et al. [16]	2023	Optimizes network usage and minimizes latency in SDN-enabled fog computing	Efficient resource allocation, Collaborative network of nodes, Fast task execution, Scalability, Flexibility, Improved Accuracy	High computational cost, select optimal ML algorithm, Integrate other emerging tech, Deployment and evaluation, Extension to multi-objective resource allocation
Lalit et al. [17]	2024	FFLY optimization technique based on firefly flashing behavior for enhanced feature selection and accuracy	Interoperability, improved reliability, energy efficiency, improved accuracy	Lack of security, limited sample size, cost, regulatory hurdles, data privacy

Lin et al. [18]	2024	Introduces the SPP-DEA metaheuristic approach for optimizing IoT service deployment in fog computing	High-quality solutions, Flexibility, Scalability, Adaptability	Based on ideal communication network, relatively small-scale IoT system, offline optimization, all IoT services are real-time

Bai et al. [14] have implemented a paillier cryptosystem that ensures privacy and data integrity in fog-enhanced IoT environments while minimizing computational and communication costs. However, limitations include specificity, assumptions about reliable servers, simulation-based results, and the need for additional feasibility studies. Zuo et al. [15] has described SIRA method, which employs deep learning and intelligent resource allocation, improves transmission delay and secrecy in fog IoT networks despite limitations such as application scope, computational complexity, resource constraints, and multiple scenario evaluations.

Singh et al. [16] have implemented a ML-based resource allocation scheme for SDN-enabled fog computing environments. The scheme improves network utilization and reduces latency, outperforming previous approaches. The benefits include efficient resource allocation, collaborative networks, quick task execution, scalability, flexibility, and increased accuracy. The challenges include high computational costs, selecting optimal ML algorithms, integrating emerging technologies, and dealing with deployment and evaluation issues.

Lalit et al. [17] has used the FFLY optimization technique is a nature-inspired approach to improving feature selection and accuracy in remote healthcare monitoring systems, with benefits including interoperability, reliability, energy efficiency, and accuracy. However, challenges include security concerns, a small sample size, cost implications, regulatory hurdles, and data privacy concerns. Lin et al. [18] has describes SPP-DEA, a metaheuristic method for efficient IoT service deployment in fog computing. It outperforms other methods by providing high-quality solutions that are flexible, scalable, and adaptable. However, limitations exist, such as a perfect communication network, small-scale IoT systems, offline optimization, and real-time IoT service dependence.

Table 1 summaries the existing research work in the field of the proposed domain. Based on a literature review, we can conclude that there are some possible solutions available for load balancing at the fog layer, but they are not scalable and issue of a very high computational cost for load balancing. That is why we need an intelligent and efficient dynamic load balancing algorithm which operates on low computational cost.

4. Proposed Approach

In the evolving world of fog computing, efficient task allocation is critical for optimal resource consumption and improving system performance. The proposed technique addresses this crucial issue by simulating work distribution to fog nodes. The proposed method is the idea of dynamically allocating jobs among fog nodes based on their current load and available capacity. The algorithm's goal is to reduce latency, maximize throughput, and assure optimal resource usage in the fog computing environment by intelligent load balancing. Figure 3 shows the architecture of the proposed fog-enabled framework for optimal resource allocation in IoMT environment.

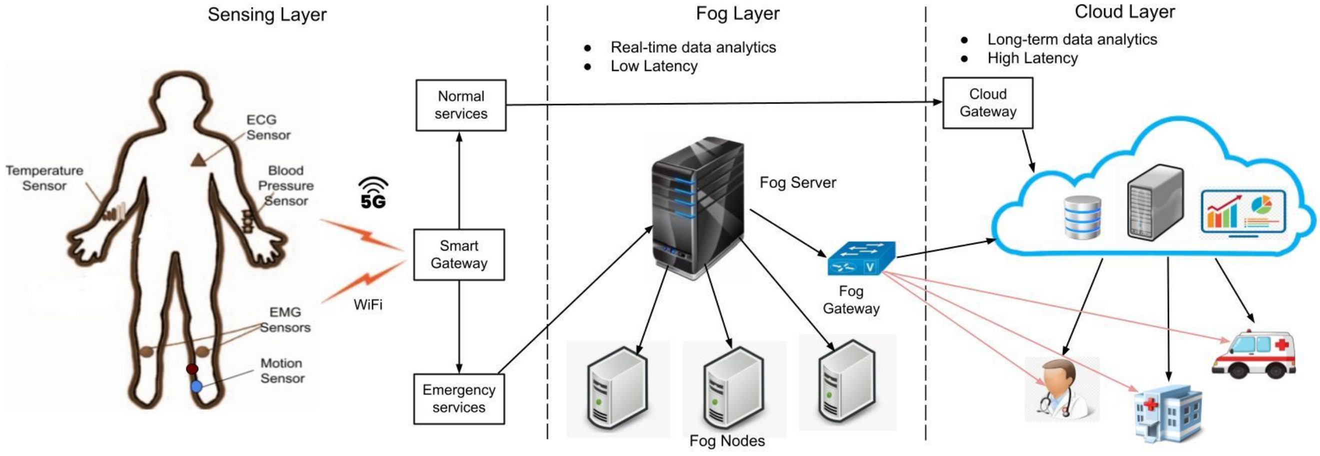

Figure 3. Proposed framework

Patient health related data collected from the sensing layer and sent to a smart gateway. Smart gateway bifurcates the data based on the criticality level and sent to either the cloud or the fog layer. The critical data will be process at the fog layer and non-critical data sent to cloud layer. The data received at the fog layer will be processed and analyzed to provide real-time treatment to the patients. The non-critical data, received at the cloud layer are used for further analysis and long-term storage. The patient's health information is accessible remotely by family members and medical personnel from both the fog and cloud layers. At the fog layer process begins with initializing fog nodes, each of which has a unique identification and job processing capacity. These fog nodes function as dispersed computing units in the fog network. Tasks are then introduced into the system, each with a unique identification and computational load. As new jobs enter the system, the algorithm assigns them to fog nodes according to their current load and available processing capability. This allocation procedure is motivated by the desire to distribute jobs fairly across fog nodes while ensuring that each node functions within its capacity restrictions.

During job allocation, the algorithm uses a complex load balancing method to maximize resource utilization. First, it determines whether any fog node has the capacity to handle the incoming task. If this is the case, the job is assigned to the node with the lowest load, ensuring that the workload is distributed evenly across the network. In circumstances where no node has enough capacity, the work is deferred for subsequent processing, preventing overload and ensuring system reliability. Throughout the job allocation process, the algorithm gives real-time information about the current load and work assignments of each fog node. This transparency makes monitoring easier and allows users to evaluate the system's effectiveness and resource consumption. Furthermore, any jobs that cannot be assigned immediately are logged for later processing, ensuring that no computational resources are misused or neglected. Fog computing systems can use this approach to optimize job allocation, resulting in increased system efficiency, lower latency, and higher scalability. This proposed method is a significant step in fog computing research, with potential applications in the healthcare industry.

5. Results and discussion

This section measures the performance of the proposed framework using latency and energy consumption. The latency includes the processing latency, transmission latency and queuing latency. Energy consumption includes the average energy consumed by the fog nodes to process the received data. Table 2 shows the experimental setup with parameters and their value used for experimentation. In the experimentation five fog node configurations namely cf1, cf2, cf3, cf4 and cf5 with 5, 10, 15, 20 and 25 fog nodes are used respectively in each configuration.

Table 2. Experimental Setup

Parameter	Value
Processor	Intel Core i5, 11th generation
RAM	8.00 GB, DDR4
Operating System	Windows 11 Pro 64-bit
Fog node configurations	5, 10, 15, 20, 25
Simulator	iFogSim

Figure 4 shows the effect of number of fog nodes on latency. The experimental results show that as the number of fog nodes increases latency decreases because more nodes will be available for processing the data. The latency increases up to optimal point and after that it increases.

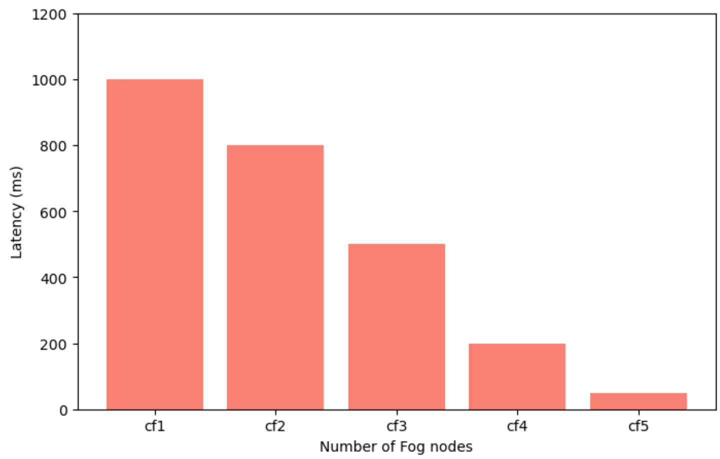

Figure 4. Latency

Figure 5 shows that average energy consumption increases as the number of fog nodes increase because of operational and idle power costs. The average energy consumption is the summation of energy consumed by all the fog nodes and energy used for data transmission.

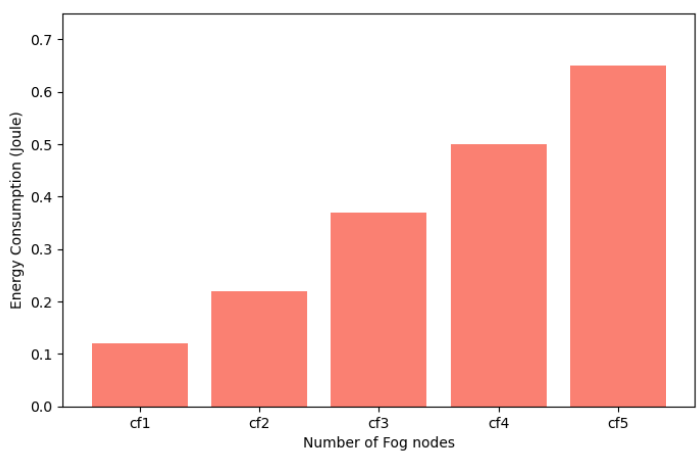

Figure 5. Energy Consumption

The experimental results show that with load balancing at fog layer we could optimize both latency and energy consumption. The optimization in both latency and energy consumption shows the better performance of proposed framework and that in turn provide the real-time healthcare to the patients.

6. Challenges and Future Research Directions

This section discusses the challenges in providing the efficient solutions to improve the healthcare services. It also covers the future research directions in the proposed domain to further enhance the performance of the framework.

6.1. Scalability

Scalability is a significant challenge for large-scale fog-enabled IoMT systems. As the complexity and size of these systems increase, traditional approaches to resource management and workload distribution become increasingly inadequate. Advanced load balancing techniques are one promising way to address scalability issues. These techniques must ensure that the system performs optimally even as it scales, efficiently distributing tasks and data across Fog nodes to avoid bottlenecks and remain responsive. Researchers and practitioners can address scalability concerns and facilitate the seamless expansion of Fog-enabled IoMT systems by implementing innovative load balancing strategies such as dynamic resource allocation and adaptive task scheduling.

6.2. Efficient Resource Utilization

Improving load balancing techniques is critical for maximizing resource utilization in Fog-enabled IoMT environments. Traditional load balancing approaches may not be adequate in healthcare settings where real-time data processing and response times are critical. As a result, there is a pressing need to improve existing techniques and create novel methodologies that are tailored to the specific requirements of IoMT systems. By focusing on resource allocation, such as CPU usage, memory, and bandwidth, healthcare providers can ensure that critical tasks are prioritized while maximizing fog node utilization efficiency. This optimization not only improves system performance, but it also helps to reduce costs, minimize latency, minimize energy consumption, and improves the overall quality of healthcare delivered to patients via IoMT platforms.

6.3. Quality of Service

Quality of Service (QoS) assurance is a multifaceted challenge due to the diverse nature of applications and the dynamic environment. Balancing the load while meeting QoS requirements necessitates sophisticated algorithms capable of responding in real time to fluctuations in resource availability and user demand. These algorithms must consider latency, throughput, and reliability when designing load distribution strategies to prioritize critical applications and improve overall system performance. Furthermore, ensuring QoS necessitates effective coordination among fog nodes to reduce the impact of node failures or network disruptions, allowing for seamless operation even in adverse conditions. As a result, achieving reliable QoS in fog computing environments necessitates a comprehensive approach that includes adaptive load balancing algorithms, effective resource management strategies, and resilient fault-tolerance mechanisms.

6.4. Security and Privacy

The decentralized nature of data processing and storage, fog computing requires a high level of security and privacy. Load balancing strategies must include strong security measures to protect sensitive data from unauthorized access or tampering, particularly given the wide range of IoT devices connected to fog networks. Encryption techniques, access control mechanisms, and secure communication protocols are critical components of load balancing algorithms that protect data confidentiality and integrity throughout the system. Furthermore, privacy-preserving techniques like data anonymization and differential privacy should be incorporated into load balancing mechanisms to protect user privacy while efficiently distributing computational tasks across fog nodes. Fog computing architectures can effectively mitigate potential vulnerabilities and enhance trust in the deployment of edge computing solutions.

7. Conclusion

The landscape of load balancing techniques for fog-enabled IoMT is a complex task with challenges and opportunities. While researchers have made significant progress in addressing various aspects of load balancing, the multifaceted nature of the challenges emphasizes the importance of robust strategies tailored to the specific needs of IoMT systems. Key challenges such as security, scalability, real-time adaptability, and energy efficiency necessitate novel solutions that incorporate emerging technologies such as artificial intelligence and blockchain. By accepting these challenges and encouraging collaborative research efforts, the healthcare industry can fully realize the potential of load balancing to improve patient care, reduce latency, and ensure the dependability of IoMT applications, ultimately improving the quality and accessibility of healthcare services for all.

Further, prioritizing research initiatives that explore the synergy between load balancing techniques and cutting-edge technologies will be essential. This forward-looking approach holds the promise of unlocking new dimensions of efficiency and effectiveness in fog-enabled IoMT systems. Through ongoing exploration, collaboration, and innovation, the healthcare ecosystem can realize a future where load balancing plays a central role in creating seamlessly integrated and responsive healthcare solutions, thus elevating the standards of patient-care and transforming the healthcare industry.

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