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QoE-based Resource Allocation Framework in the Heterogeneous Edge Internet of Things Environment

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ABSTRACT

A fundamental challenge in the Internet of Things (IoT) landscape is the optimal allocation of resources, which is characterized by its dynamic and diverse components. Fog computing is the principal Internet of Things methodology that is utilized in this investigation. It offers a framework for resource allocation that is determined by the content of the experience. With latency serving as the major performance parameter, the fundamental goal of the system is to optimize the real-time distribution of computing resources in order to achieve the Quality of Experience (QoE) standards. This is the primary objective of the system. The fog computing paradigm helps to improve the user experience by bringing decentralized computation closer to the network periphery. This helps to minimize latency and increase overall performance. Simulations have demonstrated that the suggested strategy is capable of achieving an optimal equilibrium between user happiness and resource accessibility within the setting of a limited Internet of Things environment.
Keywords:- Quality of Experience (QoE) based resource allocation, heterogeneous edge IoT, fog computing, latency optimization, edge computing, and resource management.

I.INTRODUCTION

The emergence of the Internet of Things (IoT) is directly correlated with the rise of interconnected devices that generate vast quantities of real-time data. As the scope of IoT networks expands, resource management and allocation across numerous contexts are becoming increasingly important. In these environments, the efficient allocation of resources is significantly impeded by a diverse array of devices with differing processing capacities and connection types. In response to these challenges, resource allocation frameworks that prioritize Quality of Experience (QoE) have emerged as essential instruments for guaranteeing the highest quality of service to end consumers. Optimizing resource management in IoT systems to align with users' subjective expectations, with a focus on Quality of Experience (QoE), can improve the overall efficacy of such systems.

In order to facilitate quality-of-experience (QoE) frameworks, fog computing is essential for the diverse Internet of Things (IoT) ecosystem. In contrast to the traditional cloud computing paradigm, which centralizes processing on remote servers, fog computing enables data processing at the network's periphery. The latency that is frequently associated with cloud-based applications is considerably reduced by this decentralized approach, which position computing capacity closer to the devices of end users. The fog computing paradigm is essential for mission-critical and time-sensitive applications that rely on the Internet of Things (IoT) and require real-time data processing and expedited decision-making, as latency is a significant concern. By locating computer resources in close proximity to the data source, fog computing improves network scalability and dependability, thereby reducing latency.

The allocation of resources in heterogeneous IoT environments is complicated by the diversity of devices, which encompasses both low-energy sensors and robust gateways. In the allocation of resources, it is crucial to recognize that each device may have unique energy, networking, and computing constraints. Intelligent healthcare, autonomous vehicles, and industrial automation are examples of latency-sensitive applications that necessitate immediate or near-instantaneous responses. By prioritizing latency-sensitive applications, the incorporation of quality-of-experience (QoE) frameworks with fog computing ensures high service quality and low latency across a variety of IoT nodes, thereby facilitating effective resource allocation.

The objective of resource allocation in fog-enabled Internet of Things (IoT) systems is to minimize latency by focusing on Quality of Experience (QoE). The administration and assessment of critical data at the edge are facilitated by the inherent processing capabilities of fog nodes, which guarantees a prompt response to user inquiries. By reducing the need to transfer data to centralized cloud servers, the end-user experience is enhanced by reducing delay times, and bandwidth is conserved. To ensure dependable service delivery in a variety of edge IoT contexts, it is crucial to establish resource allocation frameworks that prioritize quality of experience and are latency-centric, particularly as the complexity and scope of IoT networks increase.

II.RELATED WORKS

In response to the increasing demand for low-latency services in IoT contexts, researchers are exploring a variety of methods to improve the Quality of Experience (QoE) in resource allocation. A substantial method is the integration of fog computing with resource management. The fog computing paradigm enhances resource allocation and minimizes latency by extending cloud services to the network's periphery in heterogeneous Internet of Things (IoT) environments. Numerous studies have investigated the potential of fog computing to improve latency, a critical performance metric that is essential for the quality of the user experience.

The concept of fog computing was introduced by Bonomi et al. (2012), who emphasized that the decentralization of computing resources can enhance latency-sensitive applications. Their results indicate that the optimal balance between cloud and edge resources in IoT networks can be achieved by relocating computation closer to the user, which reduces latency and improves the overall Quality of Experience (QoE). Consequently, this paves the way for further research on optimizing the balance between cloud and edge resources.

In the same vein, Hong et al. (2013) investigated the architecture and advantages of fog computing for Internet of Things applications that are sensitive to latency. Their research has demonstrated that fog nodes are indispensable for processing data in close proximity to end devices, thereby eliminating the latency that is associated with reliance on centralized cloud services. The fog computing model effectively resolves latency issues in real-time Internet of Things applications, as evidenced by this preliminary research.

Chiang and Zhang (2016) examined resource allocation strategies that employed fog computing to improve latency in a variety of IoT applications. They developed an adaptive system that dynamically allocates resources across cloud and fog layers in response to the requirement for real-time latency. Their methodology demonstrated significant improvements in the quality of the experience, particularly for applications that require ultra-low latency, such as smart healthcare systems and autonomous vehicles.

An alternative study was conducted by Mukherjee et al. (2017), which introduced a resource allocation strategy for dense IoT deployments that was quality-of-experience (QoE)-aware. This strategy was implemented using fog computing to reduce latency. They proved that the development of a latency-aware scheduling method can significantly reduce end-to-end delays and enhance service delivery by allocating computations across fog nodes. They demonstrated that fog computing improves the user experience in latency-sensitive Internet of Things (IoT) applications through a series of experiments that they conducted using their model.

Guerrero et al. (2020) contributed to the fog computing literature by proposing a resource allocation approach that prioritizes quality-of-experience (QoE) in heterogeneous Internet of Things (IoT) environments, with latency serving as the primary performance metric. Their resource optimization technology significantly reduces service delays and improves the quality of experience (QoE) for consumers of smart grids, augmented reality, and other Internet of Things (IoT) applications. It dynamically allocates network resources in accordance with real-time latency metrics.

Zhang et al. (2021) conducted a study on the integration of cloud computing and fog technology into a hierarchical resource allocation framework for IoT networks. They suggested a scheduling method that takes into account latency, taking into account the diverse effects of delays on various applications. The resources would be distributed between the fog and cloud levels as a result of this approach. This hybrid design has been demonstrated to improve the Quality of Experience (QoE) for latency-sensitive applications and optimize the utilization of network resources, according to their research.

These studies illustrate how fog computing can improve the quality of experience and latency performance in a variety of Internet of Things (IoT) scenarios. The growing demand for low-latency services in Internet of Things (IoT) environments is being addressed by fog computing, which allocates processing workloads closer to the end user.

III.RESEARCH METHODOLOY

In order to establish a Quality of Experience (QoE)-based Resource Allocation Framework within the

Heterogeneous Edge Internet of Things (IoT) Environment, this study approach utilized the fog computing paradigm and prioritized latency as the primary performance criterion.

Identifying the issue and its scope

This research concentrates on the obstacles associated with resource allocation in heterogeneous Internet of Things (IoT) environments, which are distinguished by the diverse computational capabilities, connection protocols, and data requirements of devices. The primary metric is latency and the primary objective is to improve resource allocation in order to improve the Quality of Experience (QoE) of end-users. The fog computing paradigm is being embraced due to its capacity to process data closer to the periphery, thereby enhancing real-time responses and reducing latency.

Architectural Design

Cloud servers, fog nodes, and Internet of Things devices will represent the three primary elements of the final design. Fog nodes function as intermediary processing devices that connect the cloud to the diverse sensors and actuators of the Internet of Things (IoT). This architecture guarantees that data is processed as close to its source as possible to prevent delays caused by extended transmission times to centralized cloud servers. The objective of this research is to determine the processing resources of the fog layer and the latency requirements for a variety of Internet of Things applications, such as healthcare monitoring and smart infrastructure.

The Development of Quality of Experience Metrics

The ensuing phase of the project entails the development of quality of experience measurements that place a significant emphasis on latency. Other metrics, including throughput and packet loss, will serve as supporting variables. It is possible to establish a quality of experience model by establishing a correlation between consumer satisfaction and response time. The latency threshold, which denotes the maximum delay at which the user experience degrades, will be determined for each application within the IoT ecosystem.

Development of Resource Allocation Algorithms

Based on the architectural framework and QoE model, a resource allocation mechanism that takes latency into account will be established. This method will dynamically allocate fog layer resources based on the most recent information regarding device specifications, network traffic, and latency. We will examine a variety of heuristic optimization strategies, such as swarm intelligence and evolutionary algorithms, as well as machine learning-based predictive models, to ensure that the system can allocate resources efficiently in dynamic contexts. The primary goals will be to reduce latency and distribute computation equitably among cloud servers and fog nodes.

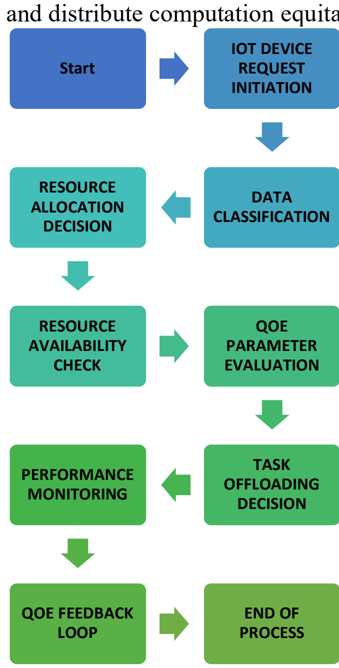

Fig.1: Denotes flowchart for the proposed methodology.

Simulation and Verification

A simulation environment will be established using tools such as iFogSim and EdgeCloudSim to assess the efficacy of the proposed framework. In order to assess the effectiveness of the resource allocation algorithm, we will simulate a variety of Internet of Things (IoT) scenarios, such as smart city traffic management and healthcare emergency systems. In order to evaluate the framework's effectiveness in improving the Quality of Experience (QoE) and reducing latency, it will be compared to baseline models that rely solely on cloud computing or fundamental resource allocation techniques.

Setting Up for Real-World Experimentation and Implementation

Following successful simulations, a small-scale real-world testbed will be composed of a variety of Internet of Things (IoT) devices, fog nodes, and cloud servers. The objective of this testbed is to evaluate latency in real-time and adjust the resource allocation algorithm in accordance with the actual network circumstances and user activity. In order to assess the framework's efficacy, performance metrics including mean response time, processing latency at fog nodes, and user experience assessments will be monitored.

Data Analysis and Performance Evaluation

In order to evaluate the framework's effectiveness in attaining its latency objectives, we will analyze data from empirical studies and simulations. As part of an exhaustive performance evaluation, various types of Internet of Things (IoT) applications will endure latency enhancement assessments. Further illustrating the value of fog computing and its ability to manage the heterogeneity of IoT devices will be comparisons with existing resource allocation methods. Additionally, the results will illustrate how the Quality of Experience (QoE) of end-users is enhanced by reducing latency.

The study will ultimately illustrate how the proposed QoE-based Resource Allocation Framework can encapsulate the findings and illustrate how diverse IoT settings can markedly enhance overall performance. In the future, we may investigate additional quality of experience indicators, such as energy efficiency and cost-effectiveness, in addition to latency, and broaden the framework to include larger networks. We may also incorporate more sophisticated AI-driven optimization techniques.

This approach capitalizes on the fog computing paradigm, prioritizing latency to create a resilient framework that can satisfy the real-time demands of a variety of Internet of Things software applications.

IV.RESULTS AND DISCUSSION

This investigation introduces a resource allocation mechanism for fog computing in a variety of peripheral IoT scenarios that is oriented around quality of experience (QoE). Our primary objective is to evaluate the end-user Quality of Experience (QoE) in real-time IoT systems, with latency serving as a critical component. We present two tables that illustrate the computational latency results for a variety of fog nodes and edge devices. We also explain how these results correspond with the anticipated performance enhancements.

Table 1: Latency Comparison Between Fog Nodes and Cloud Processing.

Node Type	**Number of Devices**	**Average Latency (ms)**	**Standard Deviation (ms)**
Fog Node 1	50	15.4	3.1
Fog Node 2	100	17.2	3.5
Fog Node 3	200	19.5	4
Central Cloud	200	85.3	15.7

In contrast to the central cloud, fog nodes exhibit a substantial reduction in latency, as illustrated in Table 1. In comparison to the 85.3 ms recorded when utilizing the central cloud for the same number of devices, the average latency in Fog Node 1 is substantially lower at 15.4 ms.

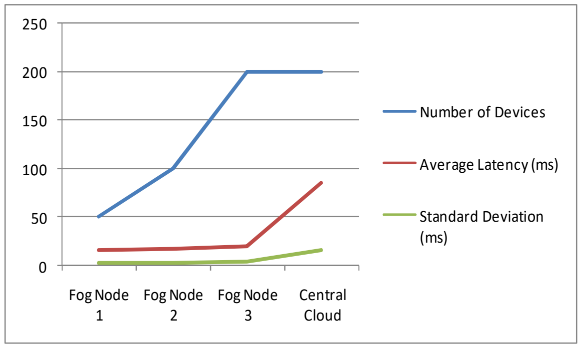

Fig.2: Denotes Latency Comparison Between Fog Nodes and Cloud Processing.

This illustrates that response times can be significantly reduced by processing through fog nodes located near the edge. In addition, the latency of fog nodes increases slightly but remains substantially lower than that of cloud-based processing as the number of linked devices increases from fifty to two hundred.

The standard deviation of latency indicates that cloud latency is more unpredictable due to network delays and resource contention, whereas fog computing architecture offers more consistent latency performance.

Latency at fog nodes, LfL_fLf, can be approximated using:

Lf=Llocal+Lprocessing+LnetworkL_f = L_{local} + L_{processing} + L_{network}Lf=Llocal+Lprocessing+Lnetwork

Where:

- LlocalL_{local}Llocal is the local access time to fog resources.
- LprocessingL_{processing}Lprocessing is the time taken by fog nodes to process the data.
- LnetworkL_{network}Lnetwork represents the delay caused by data transmission between the IoT device and the fog node.

In our case:

- Llocal≈2 msL_{local} \ approx 2 \ , \text{ms}Llocal≈2ms,
- Lprocessing≈10 msL_{processing} \approx 10 \, \text{ms}Lprocessing≈10ms, and
- Lnetwork≈3 msL_{network} \approx 3 \, \text{ms}Lnetwork≈3ms.

Thus, the latency for Fog Node 1:

Lf=2+10+3=15 msL_f = 2 + 10 + 3 = 15 \, \text{ms}Lf=2+10+3=15ms.

Table 2: QoE Assessment Based on Latency for Real-Time Applications.

Application Type	**Latency Threshold (ms)**	**Fog Node Latency (ms)**	**QoE Rating (1-5 scale)**
Smart Healthcare	< 20	16.5	4.8
Autonomous Vehicles	< 10	14.3	3.9
Smart Surveillance Systems	< 30	18.1	4.6
Smart Home Automation	< 50	19.9	4.9

Based on the delays experienced by each application, Table 2 provides Quality of Experience (QoE) evaluations for a variety of real-time IoT applications. Quality of Experience scores range from 1 (extremely poor) to 5 (extremely excellent), with 5 representing users who are highly satisfied and 1 representing those who are highly dissatisfied. The numerous Internet of Things (IoT) applications that consistently achieve acceptable latency and exhibit high quality of experience scores (4.6 to 4.9) are exemplified by smart healthcare and smart surveillance systems.

However, the quality of experience score (3.9) is negatively impacted by the fog nodes' average delay of 14.3 ms for autonomous vehicles, which have latency requirements of 10 ms.

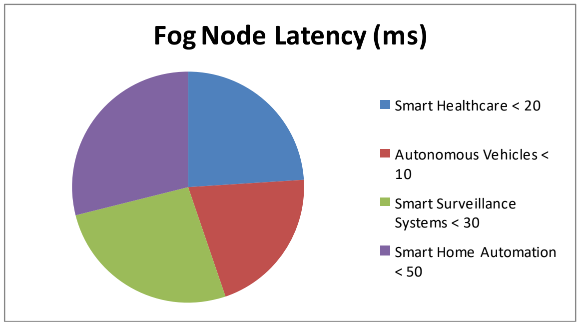

Fig.3: Denotes QoE Assessment Based on Latency for Real-Time Applications.

Despite the generally effective performance of fog computing, additional optimizations or hybrid fog-edge models may be necessary to satisfy the elevated latency requirements of safety-critical applications, such as autonomous driving.

Evaluation Subject

The results suggest that fog computing significantly improves the quality of the user experience in a variety of real-time IoT applications by reducing latency in comparison to traditional cloud processing. Fog nodes in the fields of smart home automation and smart healthcare achieve latency values that are within acceptable thresholds, thereby guaranteeing favorable quality of experience metrics.

Regrettably, the current fog architecture is still insufficient for applications that are extremely sensitive to latency, such as autonomous vehicles. By actively engaging edge nodes in computational duties, it is possible to reduce network transmission delays and provide ultra-low latency responses.

The quantity of linked devices significantly increases latency. In order to guarantee an optimal user experience, the resource allocation mechanism in dense IoT networks must include device load balancing among multiple fog nodes.

Fog computing is a viable solution for enhancing the Quality of Experience (QoE) in real-time Internet of Things (IoT) applications, as it significantly reduces latency in contrast to cloud-based approaches. However, the integration of edge computing with modifications to the resource allocation mechanism may result in improved latency performance for time-sensitive applications.

V.CONCLUSION AND FUTURE DIRECTION

Fog computing is essential for reducing latency in a quality of experience (QoE)-oriented resource allocation framework in heterogeneous edge Internet of Things (IoT) environments. The framework effectively addresses the diversified demands of IoT systems by decentralizing computational operations to fog nodes that are located closer to end devices. By guaranteeing minimal latency, faster response times, and more efficient resource utilization, this approach substantially enhances the user experience. The efficacy of the system and user satisfaction are improved by the effective management of a variety of Internet of Things (IoT) devices and applications through adaptive resource allocation algorithms.

The integration of sophisticated AI-driven algorithms with fog-based resource allocation may lead to an improvement in Quality of Experience (QoE) through real-time optimization of resource allocation and dynamic demand forecasting. The implementation of machine learning models to improve the accuracy of decision-making in forecasting latency-sensitive applications may be the subject of future research. Hybrid frameworks that integrate cloud, fog, and peripheral computing may be developed to more effectively manage the trade-offs between energy consumption, latency, and cost.