International Journal of Engineering Research and Science & Technology

ISSN 2319-5991 www.ijerst.com
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Peer Reviewed, Referred & Indexed Journal

Research Paper

INCENTIVE-VACATION QUEUEING FOR EDGE CROWD COMPUTING

NAVEEN REDDY NEMILI [1], ERLAPALLY ANUSHA [2], GURRAM VARUN REDDY [3], PATNAMSHETTY SAI VARSHITH [4]

[1]Assistant Professor, Dept. of CSE, Guru Nanak Institutions Technical Campus, Ibrahimpatnam, Telangana, India

[2, 3, 4] B.Tech, Dept. of CSE, Guru Nanak Institutions Technical Campus, Ibrahimpatnam, Telangana, India

ABSTRACT— Edge computing is designed to bring services closer to end users, significantly improving latency and scalability. However, beyond the conventional edge lies an untapped resource the extreme edge. Extreme edge computing (XEC) leverages computational power at the user's immediate environment, offering new opportunities for efficient resource utilization. Edge crowd computing (ECC) takes advantage of this by creating a sharing economy model where users can rent out idle resources on their devices in exchange for compensation. This paper explores an orchestrated ECC model that incentivizes users to provide their devices' computational power. We introduce the incentive-vacation queueing (IVQ) model, which links performance to incentive payments using a vacation queueing mechanism, factoring in device multitenancy and the dynamic nature of server availability tied to incentive levels. This framework allows for the analysis of any sharing economy system modeled by IVQ, providing insights into how incentives and server "vacation" periods influence performance. We investigate two types of IVQ functions that can be tailored to either benefit the orchestrator or the device owners and propose a performance metric to evaluate these trade-offs. Our analytical expressions account for the stochastic availability of user devices, influenced by changing incentives, and offer a comprehensive approach for evaluating system performance in edge crowd computing environments.

Index Terms – Edge Crowd Computing, Vacation Queueing, Incentive Mechanisms, Edge Computing, Resource Allocation, Task Scheduling, Queueing.

I. INTRODUCTION

CLOUD computing has emerged as a fundamental component in contemporary trade and service exchanges . Its expansion is marked by three notable trends: 1) the swift progress of the Internet of Things (IoT) and explosion in number of its devices; 2) the need for advanced applications, such as VR/AR; and 3) the imperative of ensuring security and privacy. This growth may soon surpass the centralized cloud and its backhaul network's capacity. To address this, Fog and Edge Computing have been introduced to decentralize and meet demand by bringing services closer

to users. Nonetheless, the capabilities of idle, powerful consumer devices like PCs, smart devices, wearables, vehicles, and appliances are underutilized. These devices have evolved from specialized hardware to versatile computing tools.User devices have the potential to create an underutilized tier of edge computing, which we term extreme edge computing (XEC). This involves processing done exclusively on user devices, characterized by their proximity to end-users and modest processing power. XEC harnesses collective idle computational resources across numerous devices rather than relying on singular device capabilities. This has become possible due to nascent technologies, such as unikernels and microcontainers. While inherently decentralized,XEC can also adopt a semi-decentralized architecture. Edge crowd computing (ECC) represents this semi-decentralized model, where service providers distribute their offerings through third-party devices within the user's vicinity, paralleling the service provision models of companies like Uber or Airbnb. ECCs present a notable use case in game streaming services over wireless networks. For low-capability devices like smart-phones, the service provider uses edge servers for streaming sophisticated games, aiming to reduce latency and enhance the user experience. Mobility-related connectivity issues, for instance, on a train, may disrupt service access, preventing enjoyment of the game. Although mobile devices can store the game, they often lack the necessary processing power and battery life to run it effectively. To counter unreliable connections, the service provider might transfer game assets directly

to the user's device, which temporarily coordinates gameplay by utilizing nearby devices, such as those of fellow passengers, by sharing the game's workload. These "worker" devices would receive compensation from the service provider. While not yet viable with current technology, this model is foreseen with the advent of 6G and D2D URLLC advancements in XEC and ECC frameworks. Edge Cloud Computing (ECC) is promising but comes with unique challenges. This study tackles two main concerns: 1) the need for user-owned devices to perform reliably despite being multitenant and 2) the diversity in usage, connection, and capabilities among these devices. Deploying ECC on personal devices is complex, primarily due to their and their owners' unpredictable reliability, often linked to the owners' behavior. Similar to mobile crowd sensing (MCS), which leverages incentives to manage participant engagement , we argue that such strategies can be adapted for computational tasks in ECC. However, while MCS rewards are for human input, ECC incentives compensate for any device performance dips when sharing computational tasks. Thus, incentives are crucial in ECC for converting computational resources into tradable assets. Several studies have explored Edge Computing frameworks where there is an interaction between customers and service providers. Harth-Kitzerow and Garrido tackled the issue of mutual self-interest—workers wanting maximum reward for least effort and customers wanting maximum service for least payment—by introducing a validation entity to ensure job execution fidelity by re-evaluating job samples. Additionally, presents a macroeconomic analysis based on a double auction model, focusing on enhancing social welfare considerations that align the objectives of both service providers and customers. Similarly, proposes a dynamic pricing strategy in a sharing economy context to improve social welfare.Although social welfare is an important overarching metric,it is essential to acknowledge the diverse array of more immediate system performance indicators, such as latency and throughput, especially given the variable and delay-sensitive nature of edge computing environments. XEC and ECC systems are emerging technologies that have not been extensively explored in existing research. The untapped computational resources of advanced edge devices are now more accessible, thanks to advancements in virtualization, software-defined networking, and containerization. These technologies enhance network

adaptability and autonomous organization, facilitating seamless computational handover from user devices to proximal devices. The efficacy of new semi decentralized XEC systems, like ECC, remains unquantified. Performance largely depends on workers' profit motives. Deployers of ECC orchestrators can gain from understanding the correlation between incentives and performance. This insight is crucial for reducing recruitment costs and maximizing profits while delivering services on time and to customer satisfaction. Therefore, investigating the incentives-performance relationship is imperative. This study examines ECC systems with orchestrator over-sight, where incentives mitigate uncertainty. We introduce the incentive-vacation queueing (IVQ) framework, a queueing-theory method, to evaluate how incentives influence a worker'soutput. IVQ focuses on multitenant worker devices adopting a vacation scheme, whereby the device attends to its owner's requirements post ECC service. We assess our model via vacation queueing theory, specifically the M/G/1 queue with restricted pure vacations, noting that incentives, being stochastic, alter vacation lengths.

II. RELATED WORK

A. Incentive-vacation queueing for extreme edge computing systems.

"Incentive-Vacation Queueing for Extreme Edge Computing Systems" refers to a framework in which incentive-based vacation models are applied within the context of edge computing systems, particularly those that operate in extreme environments. Edge computing involves processing data closer to the source (such as IoT devices or sensors), reducing latency and improving real-time decision-making. In these systems, the "vacation" concept typically refers to periods when certain resources or nodes are temporarily inactive or "on break," allowing for load balancing or system optimization. The "incentive" component motivates nodes or devices to enter these vacation states at optimal times, based on factors like system load, energy consumption, or computational demand. By introducing an incentive-vacation queueing model, the system can dynamically manage resource allocation, ensuring that edge nodes operate efficiently without being overwhelmed by constant tasks. This approach helps improve system performance, energy efficiency, and resilience in scenarios where extreme conditions, like harsh environments or resource limitations, are a factor.

B. Unikernels motivations, benefits and issues: A multivocal literature review

"Unikernels: Motivations, Benefits, and Issues: A Multivocal Literature Review" explores the emerging concept of unikernels, a specialized type of operating system architecture designed for minimalism and performance in cloud computing and virtualized environments. Unikernels are single-purpose virtual machines that combine the application and operating system into a single executable, leading to smaller, faster, and more secure instances compared to traditional operating systems. The motivations for using unikernels include improved performance through reduced overhead, enhanced security by minimizing the attack surface, and better resource efficiency. However, the review also highlights several challenges and issues, such as the lack of general-purpose support, limited ecosystem and tooling, and difficulties in debugging and monitoring. Despite these issues, unikernels are gaining traction in specific use cases like microservices, IoT, and serverless computing due to their lightweight nature and speed. The literature review emphasizes the importance of understanding both the advantages and the limitations of unikernels to assess their suitability for various application scenarios, contributing to ongoing discussions in the field of cloud computing and system architecture.

C. Enhancing edge computing with Unikernels in 6G networks.

"Enhancing Edge Computing with Unikernels in 6G Networks" explores the potential of integrating unikernels into edge computing environments within the context of upcoming 6G networks. 6G, expected to provide ultra-low latency, massive connectivity, and high bandwidth, is poised to revolutionize the way applications and services are delivered, particularly in fields like autonomous systems, IoT, and real-time communications. Unikernels, with their lightweight, single-purpose design, can complement edge computing by reducing resource overhead and improving performance. By embedding the application and the operating system into a single executable, unikernels can enable faster boot times, lower energy consumption, and more secure operation, which are crucial for the resource-constrained environments typical of edge nodes. In 6G networks, where the demand for high-speed, real-time data processing is massive, unikernels can optimize edge devices to handle specific tasks efficiently, minimizing latency and reducing the need for large, power-hungry

infrastructure. However, challenges like limited tooling, compatibility issues, and debugging complexities must be addressed to fully harness the benefits of unikernels in such advanced networks. Integrating unikernels with edge computing in 6G networks could thus provide a scalable, secure, and resource-efficient framework for the next generation of connected systems.

III. PROPOSED METHODOLOGY

In this article, we offer a framework for analyzing any sharing economy system that can be modeled using IVQ. We discuss the relationship between incentives and vacations on performance, namely, the incentive-vacation or IVQ function. We examine two families of IVQ functions that can be adjusted to benefit either the orchestrator or the worker and introduce a performance metric for such preference. We derive analytical expressions for system performance that consider the random nature of worker devices' availability due to fluctuating incentives. The IVQ model explores commodifying user-owned resources in an ECC system, presenting a general approach for performance analysis in such environments.

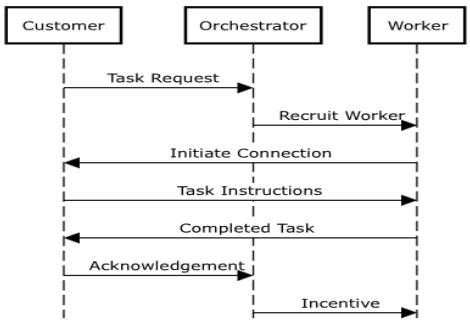
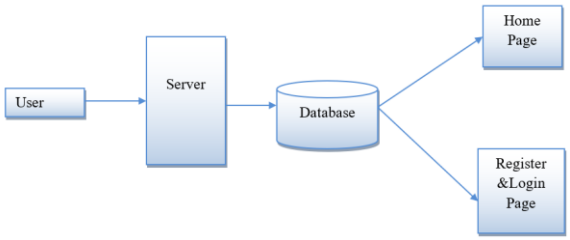


Fig. 1: System Overview

3.1 User Interface Design

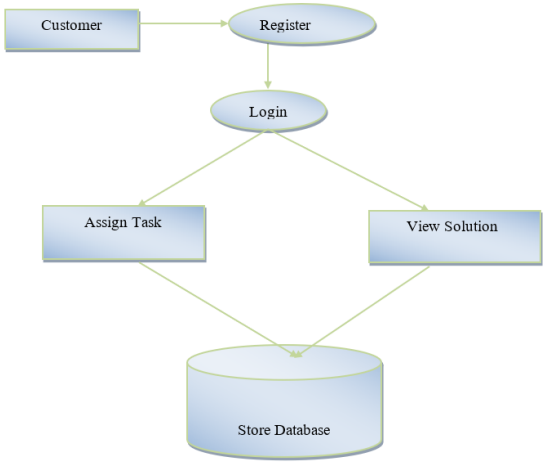
In this module we design the windows for the project. These windows are used for secure login for all users. To connect with server user must give their username and password then only they can able to connect the server. If the user already exits directly can login into the server else user must register their details such as username, password and Email id, into the server. Server will create the account for the entire user to maintain upload and download rate. Name will be set as user id. Logging in is usually used to enter a specific page.



3.2 Customer

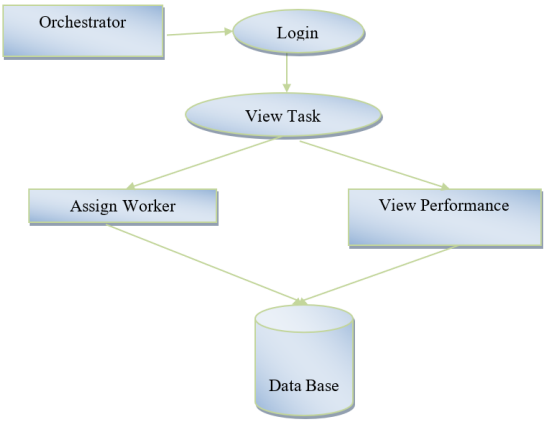
In the context of the described system, a customer plays a vital role by using the services provided by the ECC (Edge

Computing Cloud) service provider. To access these services, customers need to first register by providing essential information, including their device name and other details required for creating an account. Registration allows the service provider to associate the customer's device with their account, ensuring that it is recognized and permitted to make requests.



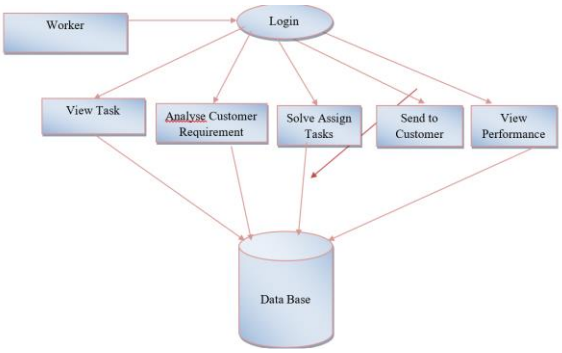
3.3 Orchestrator

The orchestrator is a central and critical component in an orchestrated Edge Computing Cloud (ECC) system, responsible for managing and coordinating the interactions between customer devices and worker devices.



3.4 Worker

In the context of an Edge Computing Cloud (ECC) system, worker devices are user-owned devices that contribute their idle computational resources to the network in exchange for incentives or rewards. These devices can include personal computers, smartphones, or other smart devices that are not being fully utilized for personal tasks.



IV. EXPERIMENTAL RESULTS AND ANALYSIS

In this article, we offer a framework for analyzing any sharing economy system that can be modeled using IVQ. We discuss the relationship between incentives and

vacations on performance, namely, the incentive-vacation or IVQ function. We examine two families of IVQ functions that can be adjusted to benefit either the orchestrator or the worker and introduce a performance metric for such preference. We derive analytical expressions for system performance that consider the random nature of worker devices' availability due to fluctuating incentives. The IVQ model explores commodifying user-owned resources in an ECC system, presenting a general approach for performance analysis in such environments.

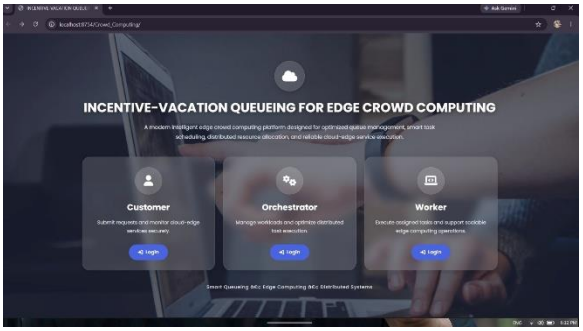


Fig. 2: Home Page

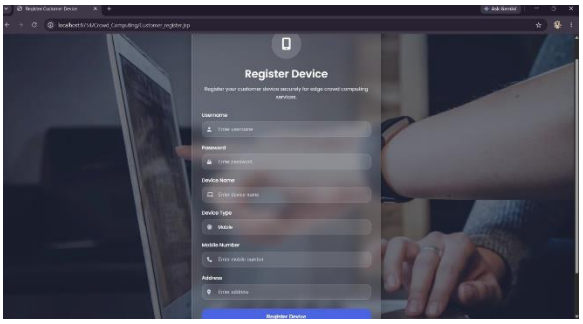


Fig. 3: Registration

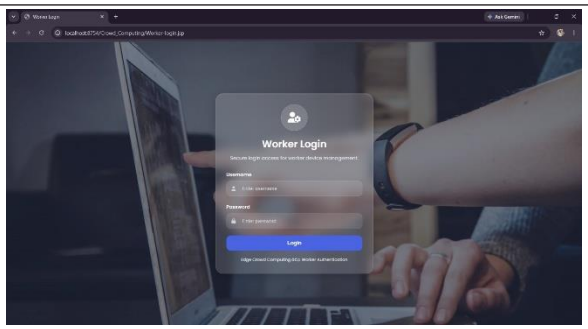


Fig. 4: Login

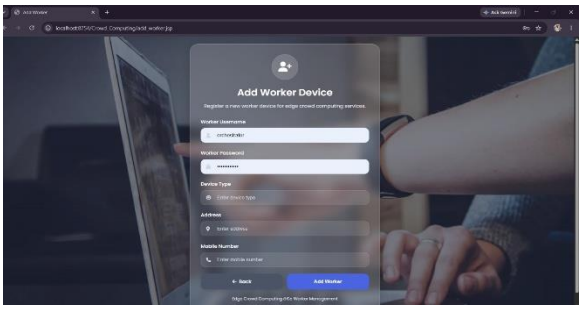


Fig. 5: Add Worker Device

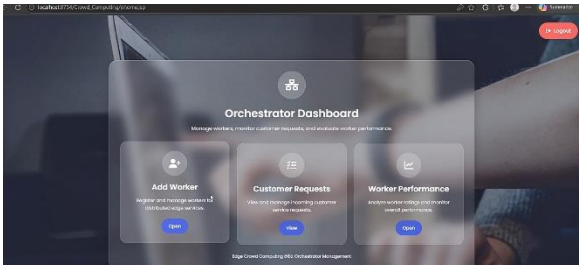


Fig. 6: Dashboard

V. CONCLUSION

The rising demand for cloud services is predicted to surpass the capacity of cloud computing. To cope with such demands, paradigms like Edge and Fog computing have physically relocated service provision closer to the customer. While this proximity achieves better latency and reduces operational costs and the burden on the

backhaul network, it necessitates more complex management. XEC represents a promising frontier in which user-owned devices, rich with resources, can be exploited for service provision, albeit at the cost of dealing with the uncertainty and unreliability of these devices and their owners. In this article, we describe an orchestrator-based edge system that rents multitenant devices from users to provide an edge service, offering an incentive in return. To serve both the extreme edge and their own users, we propose the IVQ model, which utilizes the XEC worker as a server that takes a vacation to perform tasks unrelated to the extreme edge, with the effect of incentives reflected in the length of these vacations. We model the behavior of systems through our IVQ model and derive closed-form expressions that relate the performance of such a P-Limited IVQ system with uniform incentives. It has been clearly demonstrated that increasing incentives enhances performance and reduces the sojourn time for jobs in the system. The IVQ model is useful for analyzing extreme edge systems where user-owned devices have the potential to become a significant part of the infrastructure, particularly in systems with an XEC orchestrator recruiting and distributing jobs to XEC workers.

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AUTHORS Profile



DR. NAVEEN REDDY NEMILI has received his MCA from Osmania University, Hyderabad in 2010, M.Tech degree in Computer science from JNTUH, Hyderabad in 2014 and Ph.D degree awarded in Computer Science from SSSUTMS, Madhyapradesh in 2024 He is dedicated to teaching field from the last 12 years. His research area Cloud Computing. At present he is working as Assistant Professor in CSE Department at Guru Nanak Institutions Technical Campus, Ibrahimpatnam, Telangana, India.



Ms. ERLAPALLY ANUSHA pursuing B.Tech degree in Computer Science and Engineering at Guru Nanak Institutions Technical Campus affiliated to JNTUH in 2022-2026.



Mr. GURRAM VARUN REDDY pursuing B.Tech degree in Computer Science and Engineering at Guru Nanak Institutions Technical Campus affiliated to JNTUH in 2022-2026.



Mr. PATNAMSHETTY SAI VARSHITH pursuing B.Tech degree in Computer Science and Engineering at Guru Nanak Institutions Technical Campus affiliated to JNTUH in 2022-2026.