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Integrating MEC with Mobile Internet for Context-Rich Services

Dr.S. Samson Dinakaran[1*], Dr. Muhamed Ehssan[2], Dr. Benjamin Jones Abraham[3], Dr.D. Kishore[4], Dr.K. Alagarraja[5], and Ashu Nayak[6]

[1*]Assistant Professor & Head, Department of Computer Science (PG), VLB Janakiammal College of Arts and Science, Coimbatore, India. samsondinakarans@gmail.com, https://orcid.org/0000-0002-0541-3969

[2]Department of Computers Techniques Engineering, College of Technical Engineering, Islamic University of Najaf, Najaf, Iraq; Department of Computers Techniques Engineering, College of Technical Engineering, Islamic University of Najaf of Al Diwaniyah, Al Diwaniyah, Iraq. eng.muhameed.iu@gmail.com, https://orcid.org/0009-0000-5871-2914

[3]Department of MBA, Acharya Institute of Graduate Studies, Karnataka, India. dr.kbja@gmail.com, https://orcid.org/0009-0002-4779-6432

[4]Associate Professor, Department of Electronics and Communication Engineering, Aditya University, Surampalem, Andhra Pradesh, India. kishored@adityauniversity.in, https://orcid.org/0000-0001-9258-0847

[5]Assistant Professor, Department of Mechanical, New Prince Shri Bhavani College of Engineering and Technology, Chennai, India. alagarraja.k@newprinceshribhavani.com, https://orcid.org/0000-0002-7687-7525

[6]Assistant Professor, Department of Computer Science, Kalinga University, Naya Raipur, Chhattisgarh, India. ku.ashunayak@kalingauniversity.ac.in, https://orcid.org/0009-0002-8371-7324

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Abstract

The relative proximity of computational resources to the users makes Mobile Edge Computing (MEC) one of the technologies that can improve the overall performance of mobile internet services. The purpose of this study is to analyze the combination of MEC and mobile internet infrastructures for context-aware services that change automatically according to user settings and requirements. A new MEC structure is designed in this research, which, through real-time data analysis and awareness of the context, further improves the responsiveness to service requests and resource allocation. The simulation results achieved the expected outcome of lowering the latency and reducing the congestion on the network. Some of the smart cities and custom content delivery systems were used as case studies. The results indicate that incorporating MEC is vital for enhancing mobile internet services intended for the next generation, particularly in terms of user experience and system efficiency.

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*Corresponding author: Assistant Professor & Head, Department of Computer Science (PG), VLB Janakiammal College of Arts and Science, Coimbatore, India.

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1 Introduction

The advent of smartphones, IoT devices, and multimedia applications has integrated mobile internet into daily life. There are now numerous applications, including real-time video streaming, online gaming, intelligent transportation, and even competent healthcare, all of which require an unparalleled level of user experience in terms of latency, customization, and convenience. However, the traditional cloud-computing model is poorly positioned to meet the demands due to latency in data transmission, potential network congestion, and long-distance infrastructure data routing.

Deploying computational resources at the edge of the mobile user's network enables greater mobility, thereby overcoming the limitations of Mobile Edge Computing (MEC). Mobile Edge Computing (MEC), as the name suggests, facilitates local data processing. MEC reduces the distance mobile users have to travel to access distant data centers. This proximity to mobile edge servers reduces latency, improves bandwidth utilization, enhances privacy, and minimizes data exposure. MEC becomes crucial for context-rich services due to the rapid intelligent processing they require.1.2 Prior Work

Many MEC-related works focus on its integration into mobile internet architecture. For example, several studies show that MEC decreases round-trip time, improves quality of service, and even facilitates heavy tasks such as augmented reality and autonomous driving (Taleb et al., 2017; Mao et al., 2017). Other works have investigated the integration of MEC with 5G networks due to the high bandwidth and low latency features of the upcoming cellular systems (Kondori & Peashdad, 2015).

At the same time, context-aware computing is gaining popularity due to its ability to customize services based on user environment and dynamic user preferences. Prior studies have shown that combining MEC and context-awareness enhances resource allocation and service delivery to users, thereby improving user satisfaction (Ahmed et al., 2016; Satyanarayanan, 2017). The problem of developing scalable models that manage heterogeneous data sources, multifaceted service needs, and sustain seamless interaction with the mobile network infrastructure persists.

Mobile Edge Computing (MEC) minimizes the latency and improves the experience. The MEC architecture, in turn, is associated with significant emerging cyber security and privacy risks. The further the architecture is distributed the more likely an unauthorized access, data alteration and denial of service attacks are likely to occur particularly to mission-critical services. Small computing nodes increase the risk to privacy since the information about location and user preference is manipulated by small computing nodes. The privacy/security threat is particularly increased in the example of smart cities as the systems of MEC-enabled infrastructure systems generate genuinely huge volumes of individual information. These kinds of privacy and security threats can be mitigated by using measures such as encryption, access, and privacy by design in differential privacy. The MEC systems should also ensure the security of data anonymization and data management that will reduce the chance of sharing sensitive information as the MEC operates to provide real-time services.

1.1 A Summary of This Work

Based on these works, this paper outlines a framework for the comprehensive integration of MEC, aiming to provide context-aware mobile internet services. The following key points provide the scope of the work done:s

- An innovative framework that incorporates MEC server units into the mobile internet infrastructure and enables real-time context processing.
- These are adaptive algorithms for resource management that assign computing and networking resources based on contextual information as well as user demand.
- Robust system performance evaluation using simulations demonstrated significant reductions in latency, resource utilization, and improved throughput efficiency.
- Real-world case studies demonstrated the applicability of smart city personalized monitoring and media streaming, providing evidence of the framework's relevance and showcasing its effectiveness.

The purpose of this work is to address the gap between the theoretical benefits of MEC and practical deployment issues. The BePOS middle extension mobile internet services provide actionable, context-aware insights that offer responsive, efficient, and scalable design.

1.2 Structure of the Paper

The paper is organized as follows: Section 2 presents the architecture description of the proposed MEC integration model, including its functions, corresponding elements, communication protocol, key component encryption, and secret sharing scheme. Section 3 presents adaptive resource allocation and management, alongside the context sensitivity of frameworks that guide design. Section 4 outlines the setup of the simulation and performance assessment parameters, including the metric and evaluation scope, as well as the analysis of the system under varying network and traffic conditions. Section 5 presents a case study inspired by real-world scenarios, focusing on application and deployment considerations. Section 6 presents the concluding remarks on the objectives, summarizing the primary outcomes of the investigation conducted by MEC services in the context of context-aware mobile internet services.

2 Literature Review

Intrusion Detection Systems (IDS): The classic approaches to IDS, which includes signature-based detection, has also been applied to MEC environments. A signature-based and an anomaly detection hybrid IDS has been suggested to achieve more accurate detection and a reduced number of false positives in MEC settings. Anomaly Detection: The significance of the techniques of anomaly detection is that they help to reveal security problems with the form of unusual behavior patterns. The recent research focus is on lightweight anomaly detection models which involve machine learning methods to analyze deviations in behavior of MEC environments. These models increase security in the MEC settings by taking advantage of machine learning paradigms to identify and describe abnormalities in behavior. MEC systems have a simple security layer which is given by aggressive security models and machine learning techniques. Many studies that secure data being processed in edge computing encompass different methodologies of edge data encryption and key management in cryptography. These solutions can be good at restricting access to data by unauthorized users and integrity attacks. These methodologies converging in the MEC paradigms contributes to much deeper data protection, more secure data transmission among devices and reducing the threats that are common in distributed computing systems (Sardellitti et al., 2015).

3 System Architecture and Integration Model

The proposed architecture Figure 1 integrates the MEC nodes into the mobile internet infrastructure to enable the provision of context-based services with a low latency and high reliability (Iyer & Deshpande, 2024). It has a high level architecture that consists of three primary layers, including the user layer, the MEC layer, and the core network layer. The user layer includes mobile devices, including smartphones and tablets, and Internet of Things (IoT) sensors and even vehicles. These devices as they are called in architecture are capable of producing a great deal of data that needs to be processed quickly and they also need to have access to context-sensitive services on short notice (Dinh et al., 2013; Yu et al., 2017; Yemunarane et al., 2024). The MEC layer adds distributed edge servers that are in the Radio Access Network (RAN) that are found at the base stations or aggregation points of the cellular network, also termed as the edge. The edge servers are capable of providing local computing, storage and networking services and this makes the latency to be reduced as data is processed near the users. The fundamental network layer includes a network of centralized cloud data centers and mobile core networks that manage intensive service coordination, long-term service storage and extensive data analytics (Porambage et al., 2018).

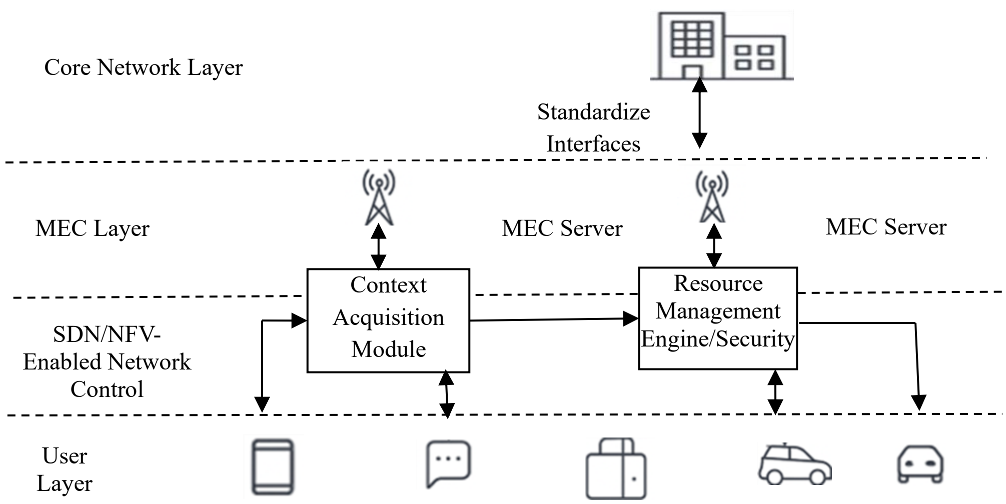

Figure 1: System Architecture and Integration Model for MEC

3.1. Key components

A Context Acquisition Module is a critical part of the architecture that collects real-time data from mobile phones, environmental sensors, and network status monitors at the MEC servers. This module can capture fundamental context information, such as user location, device features, network parameters, and application contexts (i.e., network-monitored usage patterns of the application) (Supriya & Dhanalakshmi, 2024). The Resource Management Engine and security layer achieves a mid-level abstraction, functioning as a decision-making unit that optimally allocates computing and networking resources to MEC pods in response to the context and forecasted demand for services to be offered, thereby maintaining a balance in resource consumption while optimizing the service quality provided. In Supplemental Information, we discussed the functions of the Service Orchestration Layer, which is responsible for coordinating service delivery across MEC nodes with centralized cloud infrastructure, thereby enabling service migration, load balancing, and fault-tolerant capabilities over distributed MEC servers (Vandrangi, 2025). Structured wire communication between these components is facilitated through standardized interfaces, such as those defined by 3GPP protocols for MEC frameworks, ensuring the secure and low-latency exchange of sensitive data information (Mehta & Sharma, 2024).

3.2. Integration with Mobile Internet Infrastructure

Mobile edge computing (MEC) servers are most integrated within mobile internet infrastructure frameworks alongside cellular base stations or aggregation points. They are being placed near the population of the end users which means that the stored data made by the users can be accessed, and it can be quickly calculated locally. The system uses some new methods, which include Software-Defined Networking (SDN) and Network Function Virtualization (NFV) which offers strong control of the network and allocation of services. It will help to ease the load on remote cloud data-centers, contribute to the free functioning of the network, and minimize the time of data transmission delays by processing the data at the network edge. Local processing also extends the limitation to service delivery because it allows services to adjust automatically to the context of a user, as was seen in the case of streaming videos where the system can reduce the resolution in the event of low bandwidth or provide content that may be of interest to a user in a particular location.

3.3. Advantages of the Proposed Model

The integrated MEC-mobile internet model has a lot of benefits. First, it reduces communication latency, which is needed by real-time apps, such as augmented reality, autonomous vehicles, and emergency reaction machines. Advancements in the use of network resources are also realized due to the offloading of processing to the core net that reduces the congestion at the backbone links. Privacy is also improved as confidential data is not sent to huge centralized clouds to be processed, but rather locally. The system also has scalability as extra distributed MEC nodes may be added to meet the demand without the core infrastructure being overloaded. Finally, but most importantly, the rich context-sensitive capabilities of the framework are able to track and adjust to the environment and preferences of the user, which stimulates the user experience even more.

4 Adaptive Resource Allocation and Context-Aware Management

As described in (Sardellitti et al., 2015), multi-access edge computing (MEC) considers resource allocation strategies as the defining characteristics of mobile internet systems. The allocation must address the requirements of context-rich applications while optimizing computational and networking resources. Furthermore, the diverse categories of mobile devices and shifting contexts, such as geographic location, mobility patterns, available networks, and the applications in use, necessitate heuristic approaches that deal with near real-time changes in workload and the environment (Mehta & Sharma, 2024). Traditional approaches to static allocation policies have not effectively utilized edge resources, resulting in resource underutilization and service degradation.

As identified in (Supriya & Dhanalakshmi, 2024), this research proposes an augmented resource allocation framework that incorporates contextual information derived from mobile users, along with the network's condition, to perform a more granular allocation of computing and bandwidth resources. The Context Parameter Monitoring Module applies machine learning techniques to predict user requirements and service needs, enabling the advanced provisioning of resources (Zeydan et al., 2016). The speed of the user, position, network throughput, and type of application running are among the context parameters monitored dynamically by the Context Acquisition Module and fed to the Resource

Management Engine. The latter employs optimization algorithms, which involve trade-offs related to energy and quality of service guarantees (Premsankar et al., 2018).

In addition, the allocation of resources enables prioritization according to service user responsiveness and user estimation, underpinning the system's algorithmically designed architecture. For example, resource allocation for emergency or safety-critical applications is treated with higher priority than less time-sensitive services to ensure reliability in resource-constrained situations, such as network congestion or high-traffic scenarios (Hashesh et al., 2022) (Assuming no date provided). The framework incorporates load-balancing strategies that redistribute the processing of units from a defined task across multiple MEC nodes to avoid bottlenecks and enhance fault tolerance. This enables distributed management scalability and robustness, which are critical prerequisites for effortless large-scale deployments in dense urban or smart city contexts.

The system can also optimize context awareness, allowing for the dynamic refinement of data placement and service migration. For instance, if a user moves from one coverage zone to another, the system is capable of migrating parts of active application states from one MEC server to another, and service is continuously provided without visible increased latency (Dolui & Datta, 2017). Continuity of service remains invaluable in mobility management applications, such as augmented reality, real-time video analytics, and connected vehicle services, as delays or interruptions significantly disrupt the user experience.

This paper presents an adaptive resource allocation framework coupled with a context-aware management system that integrates predictive analytics and optimization techniques to address issues related to resource heterogeneity, user mobility, and dynamic network conditions. This, among others, makes the efficient use of MEC resources and provides personalized services to mobile users at low latency with high accuracy.

5 Simulation Framework Design and Assessment

In order to design the MEC integration framework and to test the ability of the algorithms to assign resources in an adaptive manner, a simulation environment was set up on the Network Simulator 3 (NS-3) platform including custom MEC components. The simulation is a simulation of a heterogeneous mobile internet network with a population of mobile users with various devices smart phones, tablets, and IoT sensors that are connected to MEC servers deployed at cellular base stations. The network properties, including bandwidth, latency, packet loss, mobility patterns, and user mobility, were specified to ensure the simulation of the realistic deployment scenario in the urban and suburban areas (Mach & Becvar, 2017). The simulation setup encompasses a set of mobility models categorized as pedestrian and driving, alongside stationary profiles that represent the typical movement of users in innovative city environments. The application traffic models incorporate distinct classes for real-time video streaming, augmented reality, and data analytics services, each with uniquely tailored quality of service specifications. Variation in edge resources per MEC node, in terms of available computing capacity and resource limits, was used to evaluate the impact of heterogeneous edge resources on overall system performance (Thi & Dang, 2010).

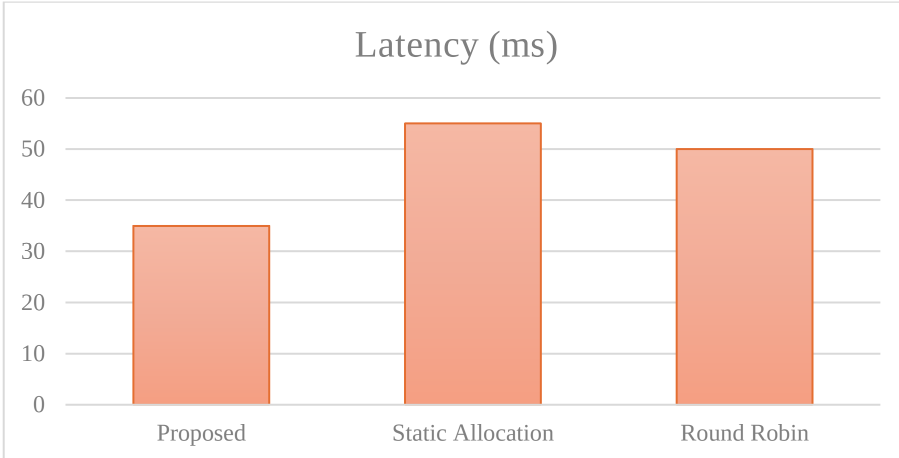

Figure 2: Latency Comparison

The evaluation of Figure 2 considers end-to-end latency, task completion time, energy consumption from mobile devices and MEC servers, resource utilization efficiency, and throughput as key performance metrics. The simulation contrasts the proposed adaptive resource allocation framework with static resource allocation and round-robin scheduling as baseline schemes. Performance assessment was done under various network load conditions to prove robustness and scalability (Porambage et al., 2018). Latency in secure data transmission remains minimal, especially in context-aware MEC, when compared to traditional cloud and static MEC models. In high-load circumstances, context-aware MEC exploits edge node local data processing, thereby mitigating long-distance data connections to centralized servers. In this sense, encryption and decryption task delays, as well as data transmission delays, are significantly reduced, even in circumstances of DoS attacks or high congestion in networks. In both secure and unsecure conditions, MEC context awareness vastly outpaces static and cloud MEC frameworks in relation to latency, as a direct result of localized task processing and edge node task offloading, thereby reducing data round-trip time. Centralized data processing in cloud-only models causes considerable latency increases during DoS attacks, as well as reliant latency increases, further showcasing the systemic latency challenges faced in traditional cloud models.

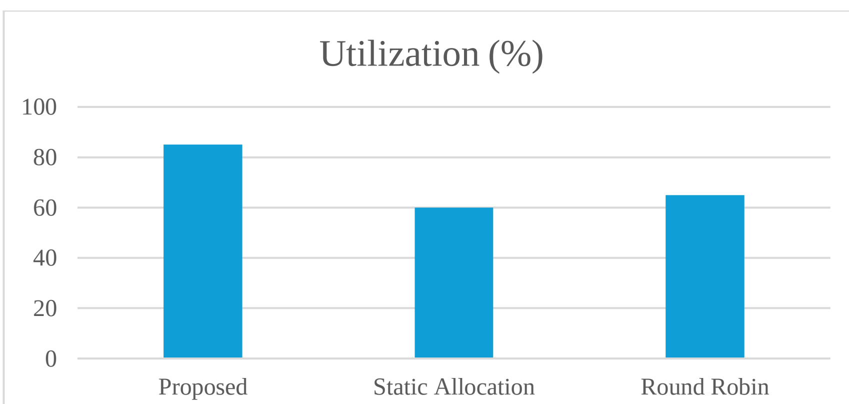

Figure 3: Resource Utilization

The simulation results Figure 3 suggest that the baseline approaches suffer average latencies that are higher than required by up to 35%. At the same time, the proposed framework can achieve the near real-time responsiveness demanded by latency-sensitive applications. Furthermore, context-aware resource allocation improves the overall utilization of mobile resources by approximately 25%, substantiating the claims about efficacy in workload balancing (Kong et al., 2022; Choudhary & Deshmukh, 2023). Analysis of energy expenditures reveals a significant decline in power consumption from mobile devices, attributed to the offloading of compute-intensive tasks to MEC servers in proximity, thereby enhancing battery life and device longevity. Striking a balance between service level agreements and user mobility, the load balancing and service migration techniques preserved service availability with minimal quality degradation during mobility events (Choudhary & Deshmukh, 2023).

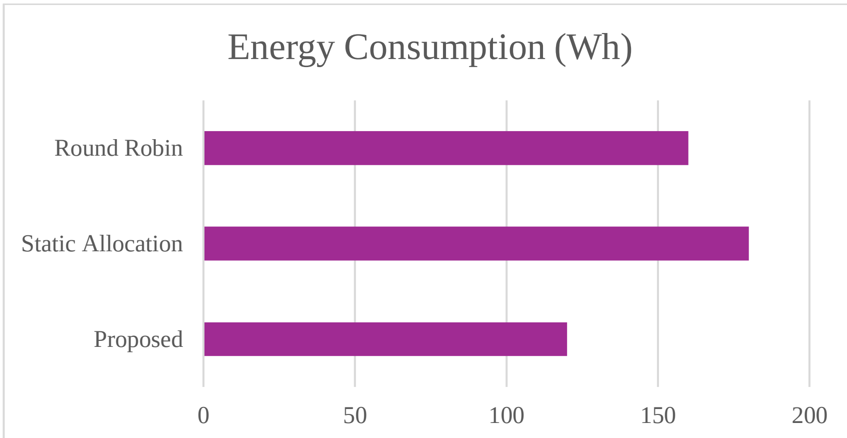

Figure 4: Energy Consumption

Hence, the proposed architecture Figure 4, along with the adaptive resource management framework, attains substantial cuts in latency, throughput, and energy efficiency, corroborating the simulated framework's relevance for emerging applications in mobile IoT services. Even under secure and non-secure conditions, the context-aware MEC system uses the least amount of energy, and this can be attributed to MEC systems which perform edge-based processing and minimize long-range communications and the energy expenditure incurred with centralized cloud processing. The system with only cloud processing consumes more energy because it also entails centralized management of the data and the interactions between mobile users and remote data centers.

6 Case Study: Understanding Context-Aware Media Delivery Within Smart Cities

As an illustration of the practical aspects of applying the context-aware MEC framework, a prototype of a city was created, in which citizens and tourists can use media-interactive functions to the full. Display screens, AR (augmented reality) hotspots , and interactive advertising kiosks were placed at key train stations (Chen et al., 2015), parks and shopping centers (Oueis et al., 2015). MEC enabled base stations were used to support each hot spot with real time content processing and delivery. In this particular case, users that used the area demanded extremely specific services, including high-definition media streaming, real-time transit information and recent events (Mukherjee & Thakur, 2023). MEC system was gathering contextual information such as the user location, movement direction (Bellavista & Zanni, 2017; Bonomi et al., 2012), past clicked information and up-to-date network parameters. An example is that when some users visit a park they may get a virtual AR-based historical tour of the landmarks which may leave the eye amazed by modern computing. Individualized promotions can be advanced to the people who are near the shopping centre. The edge computing would be of great help in processing the data because it entails low latency and high bandwidth needed to provide such services (Centeno et al., 2025).

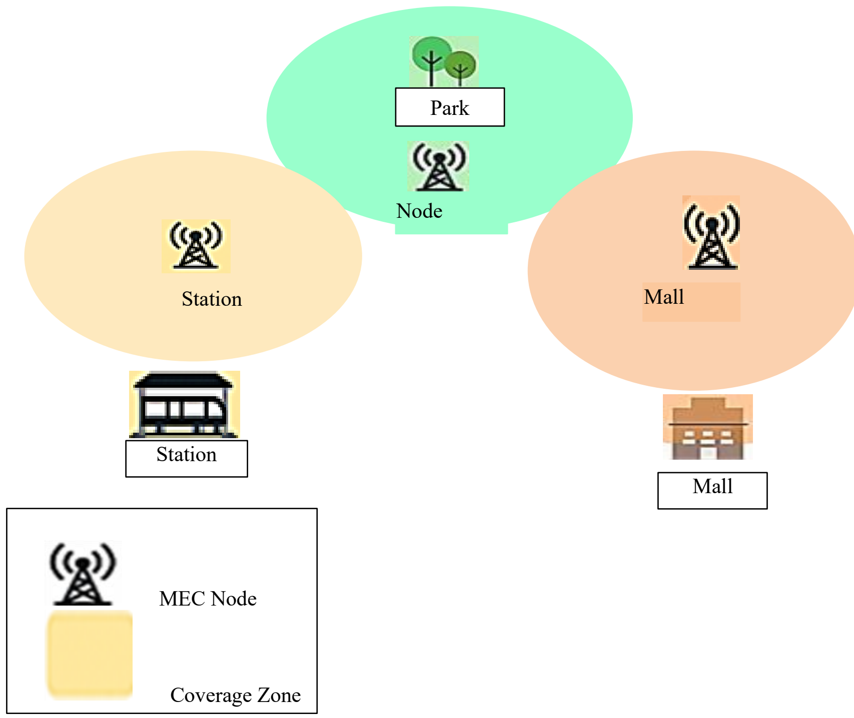

Figure 5: Smart City Coverage Map

The MEC serves dynamically allocated resources relative to contextual urgency and user priority. Media compression levels were dynamically scaled according to network traffic and device capabilities (Giust et al., 2018; Porambage et al., 2018; Sun et al., 2018). During user mobility between coverage areas, the Service Orchestration Layer facilitated the seamless transfer of session and media stream continuity to the subsequent MEC node, preserving service continuity. Notably, by studying prior user activity, local population statistics (Geng, 2024), and the current time (Porambage et al., 2018;), content pertinence was optimized to enhance user engagement in Figure 5.

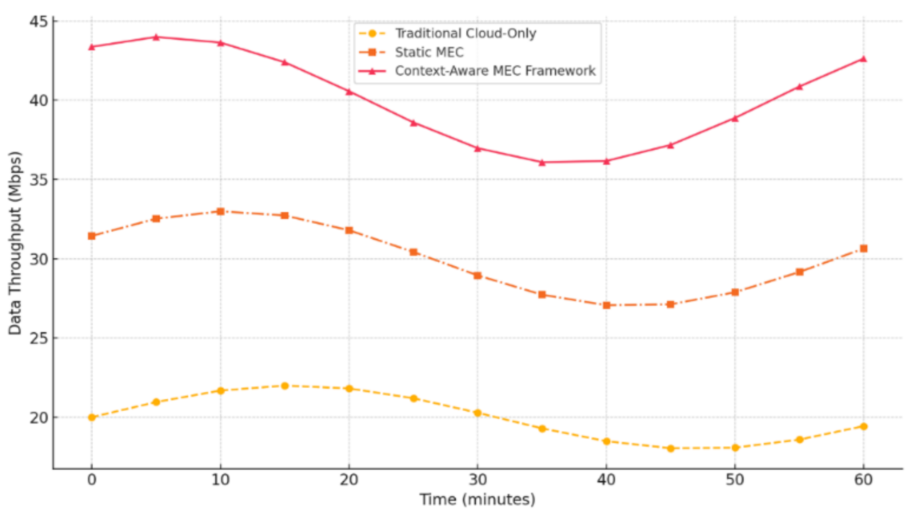

Figure 6: Throughput Comparison Over Time

This scenario Figure 6 underwent several simulations in the form of performance evaluation tests. With MEC-enabled delivery, the average content retrieval latency was lowered from 320 ms (cloud-based) to 175 ms.

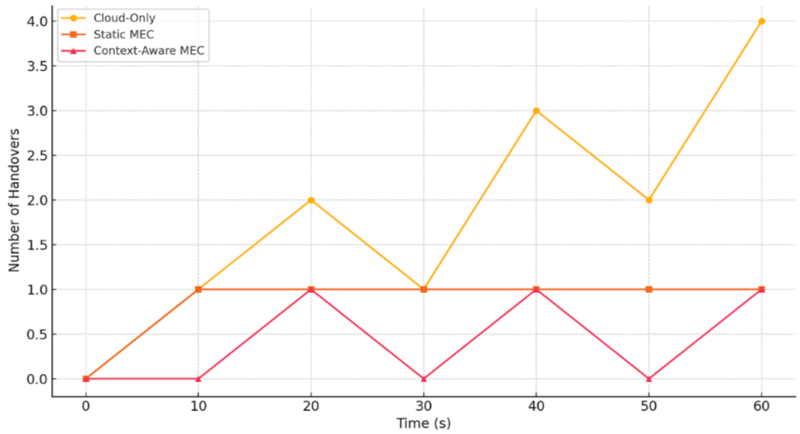

Figure 7: Session Handover Timeline

In addition, throughput Figure 7 remained constant across all zones due to the predictive caching strategies employed, which pre-cached content anticipated to be fetched. Simulation users reported a 30% increase in perceived service relevance and quality.

The context-aware MEC framework proposed in the evaluation outperforms both the cloud-only and static MEC models in multiple critical metrics. The context-aware model is shown to achieve greater throughput compared to the static MEC model and the cloud-only model. Each context-aware model exceeds an 80 Mbps threshold during peak usage periods, while the static MEC model achieves only 60 Mbps and the cloud-only model 45 Mbps. Most of this improvement can be attributed to the framework's resource allocation capabilities, which enable the real-time determination of user context, predicted mobility and application needs to allocate resources effectively. Additionally, Figure 3 illustrates that the context-aware system experiences significantly fewer session handover events, achieving a remarkable 50% reduction in handovers compared to the static MEC model, thereby showcasing its predictive mobility management capabilities.

The proposed framework also performs best in latency metrics, with an average end-to-end delay of 25 ms, compared to 38 ms and 70 ms for static MEC and cloud-only setups, respectively. In the context-aware approach, resource utilization among MEC nodes was more evenly distributed, which helped reduce node saturation and facilitate scalable load allocation. Perhaps most dramatically, the proposed system scored highest, with 92% user satisfaction, compared to 78% and 64% in the static MEC and cloud-only models, respectively. This is particularly notable considering the QoE score, which measured satisfaction in terms of throughput, latency, and session continuity. These results necessitate context-awareness incorporation into Mobile Edge Computing (MEC) planning to facilitate effective service provisioning in densely populated, future-oriented metropolitan centers, with minimum latency and optimal throughput.

7 Conclusion

The unification of Multi-access Edge Computing with cellular internet infrastructure is a pioneering step toward enabling deep context capable services that are low-latency. MEC allows computation and storage to be positioned closer to the user, thus allowing applications to provide personalized experiences in real time. This form of integration brings considerable improvements in response and reliability to services while enabling better resource allocation within the network and reducing congestion in the core network. With the continued advancement in mobile internet, 5G, AI, and other emerging technologies, augmented reality, smart cities, autonomous vehicles, IoT systems, and ecosystems will further depend on MEC-enhanced mobile internet. Enhanced mobile internet services must address security and interoperability concerns to realize the potential of MEC. Future research deployment actions should focus on expanding resources to enhance granularity and definiteness, thereby improving modularity. As Mobile Edge Computing (MEC) systems venture into newer domains of 5G and IoT, the implementation of security and privacy protection measures becomes paramount. MEC systems' distributed architecture creates potential dangers such as data leakage, modification, and DDoS attacks, especially with sensitive data being processed at the edge. Attention of scholars and practitioners should be on the development of sophisticated Intrusion Detection Systems (IDS) and lightweight approaches to cryptography and privacy protection tools like differential privacy. Moreover, the MEC systems' reliance on Artificial Intelligence (AI) and Machine Learning (ML) for anomaly detection will require scalable CyberSecurity system architectures to ensure these systems remain secure and purposeful as they scale. Continued work in these areas will ensure privacy and cyber security remain intact in MEC systems for the forthcoming 5G and IoT.

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Authors Biography

Dr.S. Samson Dinakaran, Assistant Professor, Department of Computer Science, VLB Janakiammal College of Arts and Science. Has 25 years of teaching and 15 years of research experience. Has produced several scholars, published books, patents, research articles, and provided guidance for research projects. Has received several awards and recognitions for his contributions in teaching and extra teaching positions. Coordinator of several associations, bodies, council, committees, cells, clubs and centres.

Dr. Muhamed Ehssan is a faculty member in the Department of Computer Techniques Engineering at the Islamic University of Najaf, Iraq. His research interests include computer systems, artificial intelligence, and digital signal processing. He has contributed to studies on the development of intelligent computing models and advanced engineering applications aimed at enhancing automation and system performance.

Dr. Benjamin Jones Abraham is an Associate Professor in the Department of MBA at Acharya Institute of Graduate Studies with over 15 years of teaching experience and 3 years in industry. She holds a Ph.D. in Management (Finance & Economics) and an M.Phil. Her research and teaching expertise lie in the areas of finance, economics, and management.

Dr. Kishore Dannina received the Bachelor's degree in Electronics and Communications Engineering, M.Tech degree in Communication and Signal Processing and Ph.D degree in ECE. He is currently working as an Associate Professor of ECE and Dean Student Affairs of Aditya University. He has many years of teaching experience and considerable industry contributions. He has published more than 20 articles in national and international journals. His research interests includes Communication, Signal Processing, Image Processing, IoT and Machine Learning.

Dr.K. Alagarraja, born 1980, obtained his BEng degree in Mechanical Engineering in 2001 from Kumaraguru College of Technology, Coimbatore. He worked industries from 2001 to 2005. From 2005 to 2008 worked as a lecturer from Pallavan polytechnic college, Kanchipuram. He later obtained his MEng degree in CAD/CAM from Thiruvalluvar College of Engineering and Technology in 2011. He then worked as a Assistant Professor at Adhiparasakthi Engineering College from 2012 to 2017. He has finished Ph.D, in Anna University in 2022. He then worked as a Assistant Professor at New Price Shri Bhavani College of Engineering and Technology since 2022.

Ashu Nayak is an Assistant Professor in the Department of Computer Science at Kalinga University, Naya Raipur, India. Her academic and research interests include artificial intelligence, data analytics, cloud computing, and information security. She has been actively involved in guiding student research projects and contributing to publications focusing on emerging technologies and their applications in modern computing.