Hybrid Cloud Edge Computing – An Analysis of Automation and Scalability as Features that Enhance the Model

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Abstract:
Cloud-based solutions are increasingly demanding for efficient service provisioning with challenges such as spatially distributed sensors and actuators, stringent latency requirements, privacy concerns, and transportation of large data volumes. There is an emergence of a promising complement to traditional cloud computing called edge computing, which supports computation and storage near data generation sites. With the help of the proliferation of IoT, the advancements in Multi-Access Edge Computing (MEC), and 5G mobile communication, edge-integrated hybrid cloud systems have transformed into a robust ecosystem that unifies public and private cloud infrastructures within a unified management framework. This study explores the key roles of scalability and automation within edge-based hybrid cloud systems, notably their influence on enhancing efficiency, optimizing resource utilization, and workload distribution. An evidence-based descriptive analysis evaluates the improvement of these characteristics in information and network management, identifies the most critical areas for improving performance, and investigates associated problems and risks. NOMA-MEC models find promising applications in real-time implementations such as smart cities, industrial IoT, and vehicular networks. Such NOMA-MEC models facilitate adaptive resource scaling, task automation, and seamless connectivity over heterogeneous technologies like 5G and Wi-Fi. With the integration of ML and AI-driven algorithms, mobility-related and security-related issues also get addressed, thus increasing their practical applicability. The current research underlines the demand for a standardized hybrid edge-cloud framework to optimize the scaling and automation of sustainable, efficient, and future-ready networked environments.

Keywords: hybrid edge-cloud, multi-access hybrid, scalable cloud, AI cloud, heterogeneous cloud

Introduction

Digital transformation has become integral to maintaining competitiveness and relevance in the ever-evolving realm of contemporary networking and technology. As organizations endeavor to meet shifting market demands and embrace technological progress, the importance of scalability and operational adaptability has become increasingly pronounced as essential factors for success. Cutting-edge cloud computing technologies have facilitated these goals, fundamentally altering how businesses function and expand. Digital transformation signifies a profound change in how enterprises utilize technology to optimize operations, improve customer interactions, and foster innovation.

Adding to this advancement joins the adoption of the Internet of Things (IoT), which is now growing in its application in nearly every facet of society. A few sectors that come as significant users of IoT systems include healthcare, transportation, and manufacturing. Numerous IoT frameworks incorporate devices at the network's edge, producing vast data quantities and necessitating substantial processing and storage resources [1].

This situation presents a considerable obstacle for cloud-based solutions aiming to deliver efficient service provisioning. Furthermore, challenges such as the spatial distribution of sensors and actuators, latency requirements, privacy concerns, and the transportation of large data volumes collectively drive the need for innovative solutions that complement cloud computing. The concept of leveraging resources at the network's edge, referred to as edge computing, has emerged as a viable approach to execute computation and storage near the data generation sites.

Again, the expansion of the Internet of Things (IoT) is significantly enhanced by advancements in multi-access edge computing (MEC) and the deployment of fifth-generation (5G) mobile communications. These developments offer essential architectures, platforms, and tools that facilitate the integration of IoT with cloud computing in the context of network softwarization. Presently, the deployment of IoT devices encompasses not only resource-limited sensors and actuators but also a diverse array of smart devices.

This evolution has led to the establishment of a new ecosystem in which hybrid cloud resources can operate collaboratively within a unified management framework, commonly referred to as resource continuum, cloud-to-thing continuum, or fog-to-cloud, among other terminologies. A hybrid cloud environment integrates two or more cloud infrastructures, such as public and private clouds, allowing for the seamless sharing of data and applications. This configuration offers organizations enhanced flexibility to scale their computing resources, minimize capital expenditures during peak demand periods, and allocate local resources for managing more sensitive data or applications [2].

Another significant feature incorporated in hybrid edge-cloud systems is automation. Automation of hybrid cloud implementation is fundamental for deploying infrastructure resources, establishing secure connections between various cloud environments, and facilitating data routing among sub-networks across these clouds. This automation enables users to utilize diverse resources efficiently, minimizes the need for manual intervention, and consistently fosters an environment conducive to deploying targeted big data applications [3].

Justifying all the above-stated features, flaws, and enhancements, in this research, we aim to assess the scalability and automation features incorporated in the Edge-integrated hybrid cloud system. Following the large-scale usages, diverse infrastructure, and multiple conditions in which edge-based hybrid clouds are currently being implemented, particularity, the functionalities of edge layers in its architecture, and systematic allotment of tasks to the edge, we consider the said two hybrid cloud features, scalability and automation, crucial and need thoughtful management.

Thus, in this research, through our evidence-based descriptive analysis, we aim to fulfill these goals:

1. To evaluate how scalability and automation improve the efficiency of edge-based hybrid cloud systems, especially concerning the management of information and networks.
2. To investigate how scalability and automation are critical in large edge-based hybrid cloud settings in improving and optimizing task distribution by focusing on resource usage and workload management.
3. To identify and analyze essential aspects where scalability and automation are necessary to enhance performance in managing data and networks in edge-based hybrid cloud environments.
4. We are investigating the risks, challenges, and limitations of adding scalability and automation to edge-based hybrid cloud models to document the difficulties in implementation and maintenance.

The research aims to achieve realistic goals of optimizing an edge-based hybrid cloud system that incorporates diverse technology, tools, and processes. The study outcomes will likely benefit the system in terms of cost, time, reliability, and accuracy and ensure its adoption and sustainability.

This study is structured into several sections, encompassing a literature review, identifying the research problem and its underlying motivations, the methodologies and tools employed, the results of the analysis, their interpretative discussions, and concluding remarks that outline future research directions and recommendations for improvement.

Thus, we may proceed to the succeeding sections and elaborate on the research.

Related Works

This section includes the relevant academic studies, evaluations, and findings associated with our subject of study – assessment and justification of the two most crucial features of edge-based hybrid cloud systems in terms of their efficiency in managing information and network components. To gain more profound and more precise insights on the subject of our study, we gathered scholarly articles that have elaborated explicitly on the roles, innovations, application areas, benefits, limitations, scope, and possibilities of scalability and automation in edge-based hybrid cloud systems, particularly those that are being used in large scale diverse operational conditions. Since our research aims to connect the role and efficacy of scalability and automation features in terms of information, network and task distribution and the approaches of their optimal process, we chiefly focused on scrutinizing those papers that provided discrete performance evaluation and validation of the two said features as effective for information (data)/task/network management.

The reviewed scholarly works reveal the critical aspects of edge-based hybrid cloud systems, emphasizing scalability and automation for the best performance. [4] highlights the transformative role of edge computing integrated with traditional cloud models to reduce latency and increase bandwidth. With these advancements, the approach supports latency-sensitive applications with real-time anomaly detection and monitoring in sectors such as manufacturing and transportation. However, significant obstructions exist with applications such as 3D gaming and augmented reality due to battery limitations and limited edge processing power.

[5] emphasizes the integration between IoT and hybrid cloud computing and presents a Secure Hybrid Cloud cloud-enabled architecture for IoT and SHCEI, addressing scalability, interoperability, and security issues. This architecture allows for the efficient storage and processing of data while going through the integration problem usually inherent in IoT devices. Scalability is crucial for IoT ecosystems; however, the research gaps on robust solutions that ensure seamless data sharing and management are yet to be filled.

[6] further discusses optimizing edge cloud systems in an urban environment by using geographically distributed edge clusters to optimize application response times. This paper establishes that hybrid approaches work better than purely edge deployments and can be highly efficient where the inter-edge bandwidth is poor. Nevertheless, the research identified bottlenecks within network-wide congestion from bad inter-edge connectivity.

[7] introduces auto-scaling as a significant feature for edge computing applications. He proposes a taxonomy based on dynamic workloads and decentralized environments. In this approach, container-based virtualization would offer a framework for adaptive resource management. However, more studies are required to improve the auto-scaling techniques to handle the fluctuations in workload at runtime effectively.

[8] examines the orchestration of IoT data processing in hybrid cloud-edge systems. He has concentrated explicitly on AI for the optimization of data management. Despite the central cloud system suffering from latency, the hybrid architecture allows for the integration of edge devices for real-time processing capabilities. However, the unified fault-tolerant management and dynamic relocation of data are still an open gap, which creates an obstacle to seamless integration.

[9] demonstrates a latency-aware edge computing platform for real-time applications: 3D scene reconstruction. In orchestration, the resources of heterogeneous servers use the DAGs architecture. While this dramatically reduces latency, issues are still present due to the allocation of resources in those distribution architectures.

[10] has studied fault tolerance within hybrid cloud-edge systems under the IoT Edge-Cloud Federation (IoTEF) architecture. The research has endowed automation capabilities through tools like Apache Kafka and Kubernetes in automatic reconfiguration and sound data replication. However, this work suffers from drawbacks, such as network connectivity that can be unstable and vulnerable to security, which requires more investigation to build resilience within the system.

Lastly, [11] refers to the energy efficiency of hybrid edge-cloud systems. These systems reduce hosting costs in the cloud and improve processing speeds. The author employs deep micro-moments (deepM2) to detect anomalies in energy usage. Hybrid models outperformed single models, yet such models are very computationally expensive at the edge.

As these studies collectively point out, scalability and automation may be the key to unraveling the complexities of a hybrid edge-cloud system. Some focus domains on using edge or cloud computing, real-time analytics on smart infrastructure, and anomaly detection might require orchestration or advanced knowledge in resource management along with fault tolerance. As these advances are made, scalability in hybrid systems and automatic work through them should be achievable for real-world applications.

Research Gap:

Despite all these developments in hybrid edge-cloud computing systems, several essential research gaps remain for practical connectivity, real-time evaluation, and validation of scalability and automation. The issues associated with network connectivity stability and fault tolerance remain an area of concern, which was even stressed by various studies, like [10] and [8], showing instability in networks and poor mechanisms of relocating data. Although several attempts have been made toward enhancing real-time processing capabilities, as by [8] and [9], there still needs to be robust frameworks that could dynamically adjust to changing workloads at runtime, as identified by [7]. Scalability is one of the key requirements for hybrid systems that has yet to be fully addressed.

Currently available architectures, such as SHCEI [5], do not support seamless integration and efficient data sharing at scale. Further, the computational overhead in hybrid systems [11] and resource allocation bottlenecks [9] reduce the usability of hybrid systems. Besides, automation in hybrid systems needs to be developed. The hybrid system approach, such as through reconfiguration by using Kubernetes, is presently faced with challenges of security vulnerability and the need for advanced frameworks on fault tolerance [10]. Moreover, some promising technologies are container-based virtualization [7] and AI-driven optimization, Wu (2020).

These are at an infantile stage concerning integrating real-time analytics and anomaly detection. Most of these proposed solutions have not been validated in realistic settings, nor have poor inter-edge connectivity [6], along with the computational burden of hybrid models [11]. Future work should fill in the gaps by developing and validating practical, scalable, and automated frameworks that ensure efficient resource allocation, seamless integration, fault tolerance, and energy efficiency, all of which address the demands of applications such as 3D gaming, augmented reality, and smart infrastructure.

Study Problem and Motivation

From the contemporary scholarly works, we can identify the problems that are most relevant to be sorted in the theme analysis chosen in this study:

Task Distribution and Resource Allocation –

- Weak mechanisms of resource allocation result in computational bottlenecks
- Hybrid systems suffer from high computational overhead, thus limiting their scalability and usability
- Dynamic frameworks that would be used for the adaptation of resource allocation to varying workloads at runtime are lacking

Specificity of Frameworks -

- Existing architectures, such as SHCEI [5], do not support seamless integration or efficient data sharing at scale
- Proposed solutions such as container-based virtualization by [7] and AI-driven optimization by [8] are in the early stages of development and need mature frameworks for real-time analytics and anomaly detection.
- Limited verification of these frameworks in realistic, real-world scenarios.

Networking Transparency -

- Instability in network connectivity is a significant problem
- Inter-edge connectivity bottlenecks affect the distribution of tasks and the management of data
- Dynamic relocation of data is inefficient, which affects smooth operations

Fault Tolerance -

- Current systems, like Kubernetes-based reconfiguration, lack advanced fault-tolerant frameworks
- Vulnerabilities in existing fault-tolerance mechanisms increase system instability
- Unified and reliable fault-tolerant management solutions are missing, particularly for dynamic and large-scale hybrid environments

The above-stated visible flaws indicate that the evolving hybrid edge-based cloud computing lacks compatibility regarding a large-scale, diverse network of information, task allocation, and network optimization under the said condition. Thus, our analysis aims to justify the efficacy of hybrid edge-based cloud systems in diverse enterprise ecosystems, like Smart Manufacturing and Industrial IoT, Autonomous Vehicles and Smart Transportation, Defense and Security, Healthcare Systems, Smart Cities and urban infrastructure, Energy and Utility Management, Supply Chain and Logistics, etc. [12].

We present a published justification to support our emphasis that hybrid infrastructure in edge-based cloud systems is crucial to overcoming traditional cloud-only models' cost, latency, and uptime-related limitations. According to the global market analysis, running all applications in the cloud is no longer feasible, especially

for real-time and mission-critical operations. Edge computing supports decentralized operations essential in a post-pandemic world where remote work and global collaboration are the new norms.
For instance, in matters of life and death, such as in disaster response or military operations, edge computing enhances situational awareness by processing satellite imagery and real-time GPS data locally with no delay. Similarly, wearable IoT devices, like those that monitor biometric data and autonomous vehicles, require near-instantaneous processing, which is impractical if solely dependent on cloud systems due to potential latency. Hybrid systems allow organizations to make decisions based on locally processed data while leveraging cloud analytics and storage for more extensive insights in healthcare, manufacturing, and defense. This reduces latency while improving reliability and enhancing performance; it's more than relevant in time-sensitive applications when hybrid infrastructures play a more significant competitive advantage in today's increasingly connected digital economy.

Methods and Tools

This study uses an analytical and evidence-based descriptive approach to achieve the research objectives and justify the efficacy and scope of a hybrid framework when integrated into an edge-based cloud system. Since we aim to explain two parameters, namely, scalability and automation, their scope and importance in our chosen model, a Hybrid edge-based cloud system, we've analyzed and assessed these two parameters in a model called NOMA-MEC (Non-Orthogonal Multiple Access - Multi-Access Edge Computing) and validated its role in practical purpose large scale enterprise service. The research is developed with secondary data, theories, models, and evidence collected from established and authentic research available as permitted open-source scholarly resources. We used these research findings, integrated, altered, and proposed recommendations to attain the

Findings and Discussion

In this section, we present our analysis and assessment of our selected model, NOMA-MEC, where we've segmented the section as (a) Model description, (b) Features analysis, and (c) Justification of integration of scalability and automation in NOMA-MEC.

(a) Model Description – NOMA and MEC

MEC (Multi-Access Edge Computing) – Edge-based Cloud Model

In 2014, ETSI announced an edge-based cloud computing transformation, bringing resources closer to 4G and 5G RANs, commonly called Mobile Edge Computing. MEC brings to the edge of the mobile network environment, cloud computing, and IT service environments with ultra-low latency, high bandwidth, and real-time network data. These skills help MEC carry out video analytics, IoT, AR, smart cities, healthcare, disaster management, and smart farming [12].
The ETSI MEC industry organization has renamed "Mobile Edge Computing" to "Multi-Access Edge Computing " since 2017, expanding the scope of MEC from cellular operators to other mobile technologies. MEC is committed to relieving network overload through cloud resource offloading at the edge of the mobile. Fully virtualized MEC infrastructures and scalable frameworks like SEcS address latency, fault tolerance, and resilience in distributed computing offloading.
Some significant challenges of MEC are user mobility, heterogeneity of platforms, resource scalability, and security. To provide seamless mobile services or to interact effectively with 3G, 4G, 5G, Wi-Fi, and Wi-Max access protocols, complicated frameworks would be needed. Fog-cloud interworking will be required for northbound, southbound, and east-west links. Data standardization, filtering, querying, and edge analytics integration will result in actionable insight and real-time decision-making. Industry and research collaboration must be used to standardize and deploy MEC. Autonomic computing and dynamic task execution on idle edge resources are in progress; more innovation is needed to fully reap what is now possible with various applications in many fields [13].

The table given below shows the advantages and disadvantages of MEC:

Advantages	Disadvantages
Ultra-low latency for time-sensitive applications.	Dependence on **complex system components** limits optimization.
Enhances **bandwidth utilization** for improved network performance.	Challenges in **scaling across heterogeneous platforms**.
Enables **real-time data processing** and analytics.	Limited by **resource availability** and server capacity.
Supports **user mobility** with seamless connectivity.	Faces issues in **process migration transparency**.
Facilitates **fog-cloud interworking** for efficient data sharing.	Security risks from **data breaches and intrusions**.

The table given below shows the scope and importance of MEC [13-15]:

Aspect	Details	Areas of Improvement
Scope	Used in **IoT, smart cities, AR, healthcare, and disaster management** for latency and bandwidth solutions.	Expand support for **diverse edge devices** and optimize spectrum usage.
Efficacy	Improves real-time **data processing, scalability, and analytics** while reducing network congestion.	Ensure **seamless data management** and robust resource allocation under varying workloads.
Deployment Challenges	**Heterogeneity in access technologies** (e.g., 3G, 4G, 5G, Wi-Fi) complicates interoperability.	Standardize protocols for **multi-vendor environments** to simplify integration and operations.
User Experience	Supports **mobile users** and dynamic network conditions for uninterrupted services.	Develop **transparent process migration** and enhance fault tolerance mechanisms.
Security	Ensures data safety through **fog-cloud interworking** and local analytics.	Address **vulnerabilities in edge systems** and improve encryption for secure communications.
Data Management	Involves **normalization, aggregation, and filtering** for actionable insights and decision-making.	Advanced **edge analytics frameworks** for greater computational efficiency and real-time adaptability.

We anticipate further integrating Hybrid Cloud with Multi-Access Edge Computing (MEC) for enhanced scalability, mobility, security, and resource management for next-generation networks. It combines the flexibility of a hybrid cloud with the low-latency capabilities of MEC so that resources are distributed between the cloud and the edge seamlessly to optimize computational efficiency. A hybrid cloud improves automation for MEC by dynamically scaling resources according to demand to solve problems such as heterogeneity of devices and mobility. This integration ensures constant continuity of service, supports applications requiring real-time, and makes workloads easy to offload, making MEC much more solid and responsive to the ever-evolving demands of 5G and beyond.

NOMA (Non-Orthogonal Multiple Access) Model – Hybrid Networking

NOMA is a promising technology that supports edge-cloud networking, data transmission, and large-scale enterprise scalability. Concretely, power-domain NOMA will allow multiple users to share the same frequency resources with different powers assigned to each user, improving spectral efficiency and increasing the number of connected users. This means NOMA can very conveniently be used with established communication technologies, such as OFDMA (Orthogonal Frequency Division Multiple Access), thereby making it a very useful solution for the future 5G network and beyond.

In an edge-based cloud network, NOMA integration enhances scalability by efficiently managing an exponentially increasing number of users and devices. Besides, there is support for automation that will adjust the data transfer dynamically with the channel's real-time conditions. Such makes NOMA suitable for IoT, D2D (Device-to-Device), and M2M (Machine-to-Machine) communications. Nonetheless, there are still challenges of imperfect channel state information (CSI), multi-user interference, and successive interference cancellation (SIC) errors that could limit the performance of NOMA in large enterprise settings [14].

The table given below shows the advantages and disadvantages of NOMA:

Advantages	Disadvantages
Higher Spectral Efficiency: Multiple users can share the same resources, improving network capacity.	**Interference**: Intra-user interference and imperfect SIC can reduce performance.
Increased User Capacity: Supports more users per unit of bandwidth.	**Dependence on SIC**: Performance is sensitive to SIC errors, leading to performance degradation.
Improved Energy Efficiency: Offers better energy efficiency than traditional OMA schemes.	**Imperfect CSI**: Real-time networks face challenges due to channel estimation errors.
Compatibility with Existing Technologies: NOMA can be integrated with OMA technologies (e.g., OFDMA).	**Low SNR Conditions**: NOMA may not perform well in low Signal-to-Noise Ratio environments, limiting its use in some IoT applications.
Enhanced Connectivity for 5G and Beyond: Ideal for the massive connectivity required in 5G.	**Complex Receiver Design**: This requires sophisticated receivers like SIC, which can be complex and power-hungry.

The table given below shows the scope and importance of NOMA[14]:

Scope of NOMA Integration	Areas for Improvement
Data Transmission: Efficiently handles large-scale data transmission in cloud-edge networks.	**Improved SIC Design**: Address issues with imperfect SIC decoding.
Scalability: Increases network capacity and supports a large number of devices.	**Hybrid MA**: Integrating NOMA with OMA can help optimize performance in low SNR conditions.
Automation: Supports dynamic resource allocation, enhancing system automation.	**Imperfect CSI Handling**: Develop techniques to manage channel estimation errors effectively.
Cloud Integration: Seamlessly integrates with edge-based cloud networks for optimized data processing.	**Advanced Offloading Algorithms**: Develop NOMA-based algorithms for data offloading to handle big data in 5G.
Support for 5G & Beyond: Ensures high connectivity and low latency for the massive scale of 5G networks.	**Low-Complexity Receiver Design**: Optimize receiver design to reduce system complexity.

(b) Feature Analysis of Analysed NOMA-MEC Model

The NOMA-MEC hybrid model combines the strong performance of Non-Orthogonal Multiple Access (NOMA) with Multi-Access Edge Computing to enhance the performance of communication systems in large enterprise areas. NOMA promotes an increase in spectrum efficiency that supports multiple users for transmissions on the same frequency by using power domain multiplexing, while MEC enables computation offloading closer to the users, so latency is reduced, and the rate of energy consumption will increase. This hybrid model enables multiple users to offload tasks simultaneously via NOMA uplink and offload various functions to different MEC servers via NOMA downlink. The key benefit of this hybrid model is its low latency and energy consumption compared to the conventional OMA-MEC system, thus making it an excellent fit for real-time applications and large-scale enterprise operations [15].

The table given below shows the advantages and disadvantages of NOMA:

Advantages	Disadvantages
Reduced Latency: Multiple users can offload tasks simultaneously, improving real-time processing.	**Complexity in Resource Allocation**: Efficient joint optimization of communication and computation resources can be challenging.
Energy Efficiency: By optimizing power allocation and offloading strategies, energy consumption is minimized.	**Interference Management**: SIC (Successive Interference Cancellation) technology may face challenges in complex network environments.
High Spectrum Efficiency: NOMA allows multiple users to share the same frequency band, improving overall spectral efficiency.	**Security Concerns**: Sharing the same frequency band may expose users to potential eavesdropping or security breaches.
Scalability: Can support large-scale networks due to the simultaneous transmission by multiple users.	**Computational Complexity**: High computational demands for clustering users, decoding signals, and resource allocation.
Improved Task Offloading: Tasks can be offloaded in uplink and downlink via NOMA, reducing the load on local computing.	**SIC Decoding Errors**: Inefficiencies in SIC can lead to errors in decoding, impacting overall system performance.

The table given below shows the scope and importance of NOMA-MEC [15]:

Key Feature	Scope	Efficacy
Task Offloading	Supports both uplink and downlink offloading for multiple users.	Reduces computation delay and enhances processing speed.
Resource Allocation	Joint optimization of communication and computation resources.	Improves energy efficiency and minimizes latency.
Network Management	Allows simultaneous task offloading and power allocation.	Increases network capacity and reduces congestion.
Security	Security strategies like physical layer security (PLS) for privacy.	Ensures secure data transmission in a shared frequency band.
Scalability	Suitable for large-scale enterprises and IoT applications.	Scalable to accommodate a high number of users and devices.
Latency Reduction	Minimizes task processing delay using local and edge computing.	Significant reduction in latency, suitable for real-time operations.
Task Assignment & Allocation	Utilizes advanced algorithms for task assignment and clustering.	Optimizes task completion and resource usage.
Task and Resource Optimization	Focus on balancing energy consumption and task completion time.	Reduces energy usage while maintaining high system performance.

(c) Scope and Importance of Integrating Scalability and Automation in NOMA-MEC

NOMA and MEC are transformational in the large-scale management of enterprises. However, the more critical factors are transformation in information and network management, network optimization, and advances in computation. Cache-aided NOMA has efficiency in downlink transmission and is more appropriate for vehicular networks because interference can be lessened with cached content. For example, files onboard can cancel successive interference to eliminate interference, so system performance is significantly enhanced.

Thus, with help from ML and AI, the scaling and automation in NOMA-MEC are optimized due to the algorithms with capabilities provided by ML, which, along with minimal human involvement in routing, resource, or even interference management. The dynamic nature of the environment means one can adapt parameters related to networks using reinforcement learning techniques with high mobility issues created due

to that aspect within the vehicular network being potentially overturned. Similarly, MEC supports computationally demanding tasks to be offloaded to edge servers. Therefore, this technology will reduce latency and improve efficiency [16].
However, challenges like high mobility and vastly changing topology management, resource scheduling, and routing protocols still abound. Moreover, this dynamic nature of vehicular will also demand advanced AI-driven anomaly detection mechanisms for security purposes to guarantee privacy and trust in the system. Besides, many heterogeneous connectivity solutions will need to be co-coordinated seamlessly amongst different technologies like 4G and 5G, Wi-Fi, etc, along with stringent requirements of QoS.
Advantages in edge computing will be used to create the localization of data processing in NOMA-MEC; virtualization for flexible scaling of resources in that respect, and heterogeneous resource management through multi-objective optimization frameworks will bring scalability and automation. Both enterprise and public networks would be at a new paradigm shift regarding the mode of operations regarding cost reduction perspectives, with the added enhancement of the user experience combined with computation [17].

The table below shows the NOMA-MEC model's scope and limitations, particularly justifying its use and efficacy in practical, large-scale, diverse enterprise purposes.

Improvement Areas	Existing Limitations	Practical Scope
High Mobility Management	Topology changes disrupt resource allocation, scheduling, and routing protocols.	ML-based predictive models and reinforcement learning for dynamic resource optimization.
Security and Privacy	Vulnerability to cyber-physical attacks in V2X communication channels.	AI-driven anomaly detection and advanced encryption to ensure data integrity and user trust.
QoS Requirements	Difficulty meeting diverse QoS needs in V2V, V2I, and V2X links due to varying latency and reliability demands.	Adaptive AI policies and reinforcement learning for maintaining QoS under dynamic network conditions.
Caching and Interference Management	Limited application in high-mobility and heterogeneous networks.	Cache-aided NOMA with SIC to reduce latency and alleviate interference in vehicular networks.
Scalability of Computational Resources	More support for heterogeneous resource scaling and real-time data processing in peak demand scenarios is needed.	Virtualization technologies (e.g., NFV, SDN) and MEC-based computation offloading for scalability.
Heterogeneous Connectivity	Integration challenges across access technologies like 4G, 5G, Wi-Fi, and fixed connections.	Seamless connectivity with edge-computing capabilities for diverse enterprise and public applications.
Energy Efficiency	High energy consumption is needed to maintain dynamic topologies and resource allocation.	Optimization algorithms for energy-efficient MEC server deployment and task offloading.

Conclusion and Future Possibilities

Developing NOMA-MEC models as hybrid edge-based cloud systems can change the approach toward scalability and automation requirements in this modern networked environment. The immediate objectives of such models are to figure out how factors of scalability and automation can improve edge-based hybrid cloud systems, optimize the distribution and management of tasks over workload, and identify primary areas where improvement is needed toward optimized data and network management.
Beyond adopting these technologies, critical steps must be taken to eliminate associated risks and limitations for long-term sustainability. Various NOMA-MEC models with hybrid edge-cloud systems, including vehicular networks, smart cities, industrial IoT, and other real-time processing and decision-making systems,

are seen. This model will be robust for enterprise-level and public applications where resources can be scaled dynamically with the optimization of network performance and automation of task management.
Furthermore, with the use of ML and AI-driven algorithms for predictive analytics along with dynamic resource allocation capabilities, high mobility and security challenges can be overcome. This will provide seamless connectivity across heterogeneous access technologies such as 5G and Wi-Fi. To further enhance the practical utility of NOMA-MEC models, it is recommended that a standardized hybrid edge-cloud framework with scalability and automation features be used. This includes implementing virtualization technologies such as NFV and SDN, strong optimization techniques for energy efficiency, and adaptive AI-based solutions for real-time QoS management. By facing all present challenges and developing hybrid edge-cloud integration, NOMA-MEC models will achieve optimal performance and define the new standard for scalable, automated, and efficient network and data management for future-ready applications.

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