# MEC in the 5G Era: Enhancing Reliability Through Backup Strategies and Technology Integration

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**ABSTRACT**

Understanding the unique features of Multi-access Edge Computing (MEC) in the context of 5G is key, as they enable applications such as real-time analytics. This paper explores the integration of 5G technologies with MEC and the challenges in deploying and maintaining MEC infrastructure, recognizing the impact on network reliability. In particular, the paper considers potential failures in MEC and their broader consequences on overall network reliability, proposing the strategic use of backup resources as a proactive solution to fortify MEC resilience. MEC, evolving as an ecosystem to integrate telecommunication and IT services, establishes a cloud computing platform at the edge of the radio access network (RAN), enhancing storage and computational capabilities with reduced latency for mobile end-users. The analysis covers key technologies enabling MEC integration with 5G, including software-defined networking (SDN), network function virtualization (NFV), and network slicing. The deployment of Network Services (NS) through virtual network functions (VNFs) is explored for latency-sensitive communication services, acknowledging the vulnerability of softwarized and cloud services to failures. Reliability emerges as a major challenge in MEC 5G networks, prompting the proposal of redundancy (backup) as a solution to enhance communication service reliability, setting the stage for further research considerations in MEC reliability.

**Keywords**: MEC, SDN, NFV, VNF, Softwarization, Reliability.

## 1. INTRODUCTION

The fifth-generation cellular network (5G) technology delivers unprecedented quality of service (QoS), including high data rates, reliability, and low latency, catering to various use cases such as enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (uRLLC), and massive Machine Type Communications (mMTC) [1]. However, implementing 5G services presents challenges for telecommunication infrastructure providers, particularly in terms of operational expenditure, maintainability, and efficiency. Multi-access Edge Computing (MEC) emerges as a pivotal solution, utilizing edge networks as miniature data centers to process and analyze data locally, reducing latency and offering benefits like minimized traffic congestion and lower data transmission [2]. Yet, the dynamic nature of MEC, relying on virtualization, introduces complexities and reliability threats, including software bugs and security vulnerabilities [3]. This paper aims to explore and address MEC software reliability challenges in the context of 5G networks, highlighting the significance of foundational technologies such as Network Function Virtualization (NFV), Software Defined Networking (SDN), and Network Slicing (NS) in supporting the integration of MEC with 5G [4]. The main contributions of this article are:

- We present the typical features of MEC, and key enabling technologies when applying MEC in 5G, respectively.
- We also discuss MEC complexity and challenges currently confronting MEC.
- Additionally, we consider some MEC failures and solutions in order to address the failures.

The remainder of this paper is organized as follows. Section 2 presents the MEC features. Section 3 describes the key technologies that enable MEC to be applied to 5G. Section 4 analyzes the challenges and complexity of MEC when applying it in 5G, as well as failures and their proposed solutions. Finally, Section 5 draws a conclusion.

## 2. MEC FEATURES

In this section, we outline the typical features of MEC within the specific context of 5G, specifically designed to meet the demands arising from the integration of MEC, 5G, and IoT. MEC strategically situates itself within the Radio Access Network (RAN), ensuring close proximity to end users. It excels in providing low-latency services by offloading computation-intensive tasks to nearby MEC servers within the edge network, avoiding central server reliance. MEC ensures high bandwidth, directs data to local servers within the edge network, and facilitates on-device and edge-based Artificial Intelligence (AI) and machine learning, enhancing response times. It determines user's location for location-based services, efficiently offloads computation-intensive tasks, and scales easily to

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accommodate a growing number of connected devices. With enhanced security measures, customized network slices, and real-time data analytics capabilities, MEC significantly contributes to the success of 5G networks, offering faster, more responsive, and customized services while improving network efficiency and security [5].

## 3. MEC FOR 5G: Enabling Technologies

The key technologies that facilitate the integration of MEC with 5G and IoT are presented in this section.

### 3.1 SDN

SDN technology contributes to network intelligence, programmability, and openness. It achieves these by separating the data plane from the control plane. The SDN controller, located on the control plane, gains a comprehensive view of the entire network, allowing for effective network management and control. By shifting control functions to software-based controllers, SDN has accelerated the evolution of network software. In the context of MEC, SDN serves as another critical enabling technology, enhancing the management capabilities required for MEC platforms. With the migration of software functions to SDN controllers, these controllers need to establish frequent communication with data plane devices. As a result, SDN controllers should be positioned near data plane devices to meet latency requirements, aligning with MEC's principle of placing resources near end devices to offer low-latency services. Furthermore, the widespread adoption of SDN across various domains further promotes the integration of MEC [6].

### 3.2 NFV

NFV replaces hardware infrastructure with virtualization software, decoupling network functions from physical elements and executing them on cloud infrastructure. In the context of 5G, NFV contributes to building a distributed cloud, enhancing scalability, dynamicity, and flexibility. NFV and SDN complement each other, with NFV isolating network functions and relocating them to the cloud, distinct from SDN's separation of control and forwarding functions. NFV enables the decomposition of services into Virtualized Network Functions (VNFs), allowing for their sequential execution through Service Function Chaining (SFC) without the need for new hardware. NFV-enabled MEC has been a focus of research, enhancing flexibility and resource allocation in meeting latency requirements by placing MEC services on nodes capable of virtualizing their resources [7]-[8].

### 3.3 NS

Network slicing in 5G is a pivotal feature that allows the creation of customized virtual networks, referred to as slices, on a shared physical infrastructure. Each network slice can be individually tailored to meet specific performance, latency, and bandwidth requirements, providing a dynamic and flexible framework for 5G networks. By integrating network slicing and MEC, service providers can efficiently allocate resources, customize services, and maintain the security and isolation of different MEC applications. This relationship between network slicing and MEC strengthens the capabilities of 5G networks, empowering them to cater to diverse and latency-sensitive use cases, from IoT and Industry 4.0 to augmented reality and real-time analytics [9].

## 4. MEC CHALLENGES

Integrating a MEC platform in mobile networks poses challenges in orchestrating services driven by resource fluctuations and dynamic radio conditions. Prioritizing resource allocation and service placement is crucial for efficient network use, ensuring Quality of Experience (QoE) and reliability. The most important challenges are as follows:

a) **Dynamic Resource Allocation**: Efficiently managing and reallocating computing, storage, and network resources in response to changing application demands and network conditions to prevent resource shortages or over-provisioning.
b) **Service Placement Optimization**: Selecting the optimal edge or location for deploying applications to minimize latency, maximize resource utilization, and improve overall service quality which can be vital for enhancing the user's QoE. An optimization study has been detailed in [10] to determine the optimal edge positions that suit the varying resource demands.
c) **Edge Node Selection**: Opting for the allocation of the nearest MEC that provides the requested service is generally favored for performance reasons, such as minimizing delay. Nevertheless, employing such a strategy might result in inefficiency, especially when the load on the edge is not taken into account. Choosing the appropriate edge node based on factors such as proximity, available resources, user requirements, and network conditions, while ensuring load balancing across the edge infrastructure is of great importance [11].
d) **Service Reliability and Availability**: Ensuring reliable and available MEC services involves implementing fault tolerance mechanisms to address failures, outages, and varying network conditions. The widely used checkpointing technique, creating regular snapshots of the application state, allows for

application resumption in case of failure. However, in mobile environments, frequent checkpointing due to dynamic network conditions raises scalability concerns.

### 4.1 MEC Failure and Its Potential Impact

Failures in MEC systems can stem from diverse factors, including software issues, misconfigurations, cyber threats, overloading, hardware problems, and power outages. Additional causes encompass network congestion, resource exhaustion, environmental factors, vertical and supplier issues, capacity planning, scalability, and interoperability challenges. Software aging, characterized by the accumulation of internal errors in long-running SFCs, particularly at the network edge, poses a significant threat to the dependability of MEC-SFC services, impacting user QoS and QoE. The resulting challenges in MEC resilience necessitate a comprehensive approach, combining proactive measures like configuration management and cybersecurity with reactive strategies, including redundancy and disaster recovery planning, to ensure continuous availability and reliability of MEC services [12].

### 4.2 Focus on Maximizing the Reliability of the Whole Network

In ultra-dense 5G networks, MEC nodes are strategically installed at base stations or multi-technology aggregation sites, such as access points and micro data centers. These nodes can virtualize resources into slices, each serving different end-users and supporting VNFs or SFCs. MEC servers at the network edge cater to local users and applications, with orchestration and management tools ensuring deployment based on factors like network conditions, resource availability, and real-time demands. Dynamic orchestration is crucial for maximizing service reliability. MEC system failures may result from hardware breakdown, software malfunction, or resource overflow, leading to overload. To address failures, recovery schemes involve offloading work to neighboring MECs or using user devices from adjacent MECs as ad-hoc relay nodes. Implementing redundant resources can enhance network tolerance and service reliability, albeit at a higher cost [13].

Effectively addressing infrastructure failures involves deploying robust network strategies, such as backup nodes in SFCs. In case of primary SFC failure, a backup SFC swiftly takes over, ensuring quick adaptation and fault tolerance. The backup SFC monitors state changes in protected primary SFCs, enabling seamless traffic transfer. Successful backup depends on reserving adequate resources for each primary node [14]. Masoumi *et al.* analyze two protection methods: dedicated SFC and shared VNF protection [10]-[11]. Dedicated protection incurs higher costs, while shared protection offers a resource-efficient strategy. Shared backup VNFs can protect multiple primary VNFs across different SFCs and MEC sites. However, challenges arise in resource reservation for both primary and backup SFCs upon service requests, leading to denials if resources cannot be allocated for either component. This approach contributes to ongoing discussions on enhancing the reliability and resilience of network infrastructures.

Ensuring reliability and minimizing latency pose significant challenges in 5G-edge networks enabled by NFV, potentially resulting in customer dissatisfaction and revenue decline. Typically, redundancy (backup) is employed to enhance the reliability of communication services, but it comes at the cost of additional resources. In [15], the authors tackle the issue of SFC in softwarized 5G networks, aiming for reliability, guaranteed delay, and efficient resource utilization. They introduce a novel SFC approach which optimize resource utilization and improve service chain reliability without using backups. This technique entails partitioning the VNF of an SFC into multiple smaller-capacity VNFs and connecting them in parallel which is referred to as subchaining. In subchaining, each reduced-capacity VNF maintains the same software functionality as its original counterpart. If an SFC is divided into a number of subchains, each subchain of the SFC can be modelled as tandem of M/M/1 network of queues. Moreover, the authors consider that if the reliability criteria are not satisfied with the subchaining method, backups to VNFs are introduced to meet the reliability requirements. Then, two ways of assigning backups to an SFC are proposed in this work. One way involves allocating a dedicated backup for each VNF within the SFC. Another way of adding backups for service continuity is to assign an entire SFC as backup. The backup SFC will be activated if there is a failure in a VNF component of a primary SFC. Bai *et al.* [12] propose proactive rejuvenation techniques, such as failover, to protect MEC-SFC services from aging-associated failures and attacks. These measures effectively reduce system downtime caused by SFC failures, enhancing the end-to-end dependability of MEC-SFC services. Using a Semi-Markov Process (SMP)-based modelling approach, the study assesses the effectiveness of these techniques, addressing challenges like analyzing the impact of time-varying system parameters, capturing variations in abnormal and recovery behaviors among individual SFCs, and understanding how SFC states influence end-to-end reliability and availability. The research emphasizes the degradation risks in service provision due to aging in resource-constrained MEC environments and highlights challenges in capturing time-dependent behaviors between SFCs and addressing event-time intervals through non-exponential distributions. Overall, the study underscores the significance of proactive rejuvenation for robust and reliable MEC-SFC services, acknowledging and addressing modelling challenges.

## 5. CONCLUSION

Our exploration of MEC infrastructure has provided us with potential and, simultaneously, challenges that must be navigated for optimal performance. The unique features of MEC, coupled with the enabling technologies within the 5G networks, promise revolutionary advancements in real-time applications and connectivity. However, as we dissected the challenges associated with MEC deployment and maintenance, we identified possible challenges that could endanger the reliability of the entire network. Our examination of MEC failures underscored the critical importance of fortifying network reliability. Recognizing the impacts of failures, we highlighted strategic solutions, particularly the use of backup resources, as an approach to mitigate disruptions and enhance the resilience of the MEC ecosystem. This paper has not only provided insights into the complexities of MEC but also reviewed practical strategies aimed at optimizing its reliability. As industries increasingly rely on MEC for a spectrum of applications, from real-time analytics to augmented reality, building a resilient foundation becomes imperative. Understanding MEC features, addressing the challenges, and offering innovative solutions is necessary to create robust and dependable MEC infrastructures for the digital era and beyond.

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