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TOPICAL REVIEW

Multi-Access Edge Computing Handover Strategies, Management, and Challenges: A Review

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ABSTRACT The deployment and operation of Multi-Access Edge Computing (MEC) at the network edge provides low latency computing and storage services for end user devices. Support for device mobility is a functional requirement for MEC and a handover strategy that supports the movement of device and application state between MEC nodes is an underlying technology. The handover strategy utilizes an MEC node selection technique and a handover technique to provide a smooth transition between one MEC node to another. Research into MEC handover strategies has focused on algorithms, queuing, and other considerations. The migration of the MEC device and application state is a complex process that requires resource allocation in the destination MEC node that could involve provisioning application instances and, in some scenarios, support for containers or Virtual Machines to be received from the originating MEC node. This paper reviews MEC handover strategies and provides a description of the MEC reference architecture and proposed handover algorithms and techniques found in the literature. MEC handover challenges and gaps in the body of knowledge are discussed to provide guidance for future work.

INDEX TERMS Handover, multi-access edge computing, handover protocol, state relocation, edge network, cloud computing, application migration.

I. INTRODUCTION

Multi-Access Edge Computing (MEC) is defined by the European Telecommunications Standards Institute (ETSI), formerly known as mobile edge computing. ETSI renamed it to express the growing interest of non-cellular operators to provide services and applications at the network edge. Along with the mobile edge cloud capabilities, MEC provides low latency and compute and storage capability for end users and Internet of Things (IoT) devices. An important aspect of MEC deployments is to provide end users with cloud computing services at the edge of the Radio Access Network (RAN) [1], [2], [3], [4].

MEC is an advanced approach to extending cloud computing to the network edge. MEC permits devices to utilize or share services and applications that are an extension of the cloud or data centers whilst traversing the network via the RAN or other wireless or satellite networks. By allowing RAN operators to supplement the existing Base Stations (BS) with edge computing functionality, MEC merges a decentralized computational architecture with 5th Generation (5G) mobile cellular networks to extensively improve service and application performance. Positive improvement in user experience, resource utilization, and network performance, including in the transit and core networks, are goals for MEC [5], [6]. The market demand for MEC solutions to support different industries and business collaborations, as well as in education, health services, smart homes, and many other use cases, is shown in Fig. 1.

The MEC architecture enables a flexible allocation of resources to support different services and applications. The resources include computing, storage, and networking.

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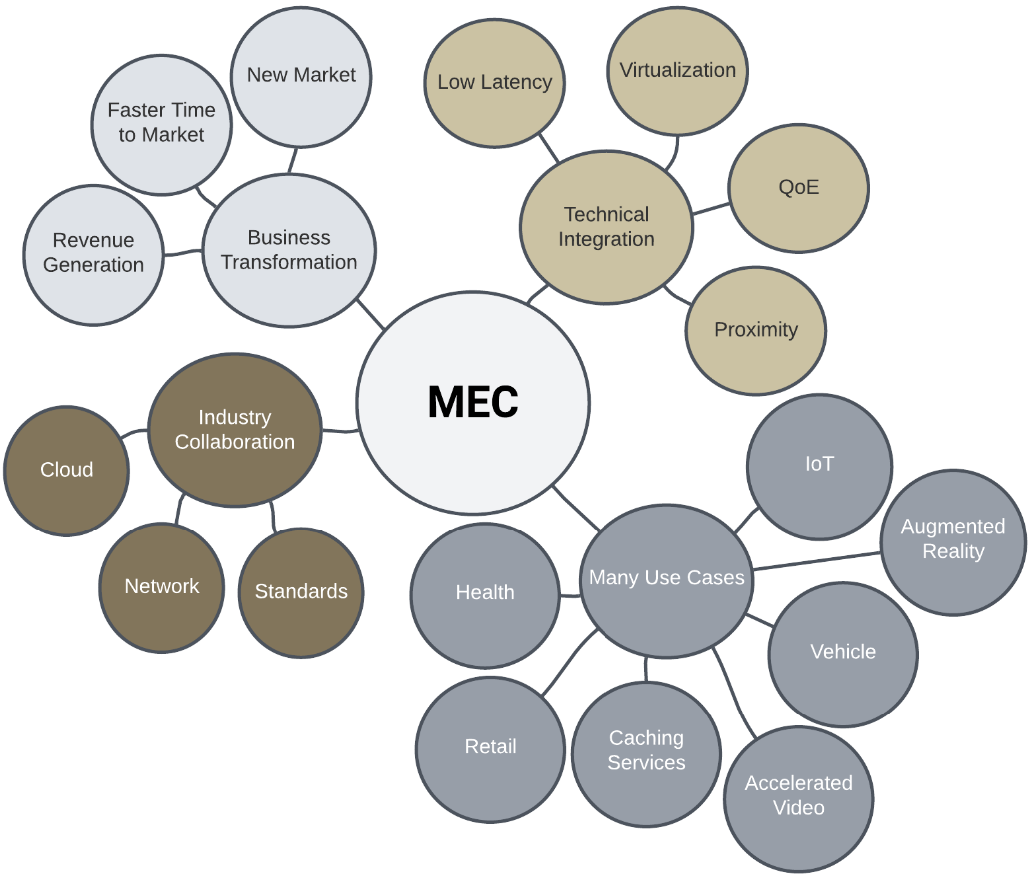

FIGURE 1. **MEC use cases in different applications [7].**

Functionality is provided to support interaction with cloud facilities, services, and applications. The typical MEC services and applications include network management and monitoring, edge content delivery, offloading, environmental monitoring, military surveillance, distance learning, mobile gaming, vehicle self-driving, mobile healthcare, edge video analytics, and much more [1], [8]. Edge content delivery is one use case for deploying cloud services to MEC nodes to reduce traffic in the transit and core networks. MEC provides an improved user experience by supporting web content caching at the network edge, optimising network performance, and reducing network cost and traffic latency are motivators for MEC [1].

Another MEC use case is augmentation, which is the delivery of information to the Application Service Providers (ASPs) that can be used to adapt their service strategies in real-time. MEC services and applications comprise underlying technologies with specific strategies to manage resource utilization and optimize networking.

MEC supports mobility and low latency by transferring devices to an adjacent MEC node and relocating the services and applications being utilized by a device ensures session continuity [9], [10]; the process is called a handover. In wireless communication, it is the process of utilizing user, data, or application session management at a BS to migrate to another [11], [12]. Handover, when applied to MEC, is used to migrate a connected device to a destination MEC node and in the process to move the state information of services and applications accessed by the device [8], [13]. The purpose of handover is to ensure that devices can be provided with services and applications by MEC nodes and move around a network without session interruption [14].

Handover in MEC exhibits notable similarities to the handover process in mobile cellular networks and other wireless access technologies, where end user radio links maintain connectivity when migrating from one radio terminal to another [15], [16]. The handover process initiates when the Received Signal Strength (RSS) has degraded and an alternative is available, which is the case near the cell boundary. There are two handover types known in mobile cellular networks: a Soft Handover (SHO) and a Hard Handover (HHO) [17]. The handover types have advantages and disadvantages, where the handover initiation decision is based on measuring parameters related to the network and radio strength, e.g., the physical distance between the mobile device and the BS, the distance between the BS, the RSS, and

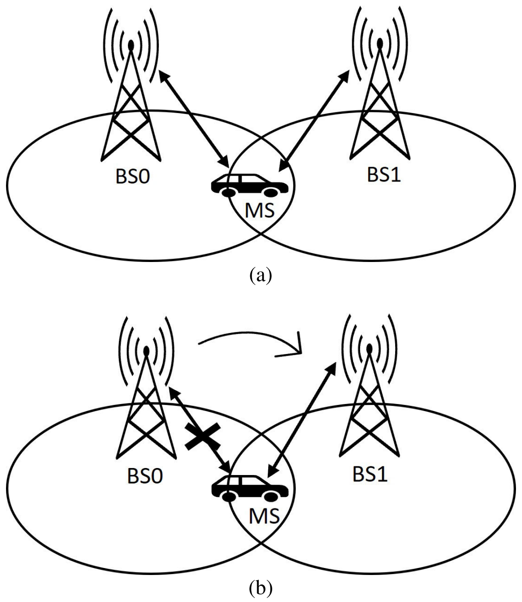

FIGURE 2. Handover types of mobile systems a) SHO; b) HHO.

the Bit Error Rate (BER). The SHO is ideally initiated when two BSs are simultaneously connected to one mobile device. In contrast to SHO, HHO is initiated when the connection between the BS and the mobile device is interrupted, forcing the mobile device to seek a new connection. HHO can result in higher packet loss and a degraded Quality of Service (QoS) compared to SHO [15], [17], [18]. The two handover types are illustrated in Fig. 2. As depicted in Fig. 2a, HHO happens after the Mobile Station (MS) is disconnected from the old BS, while SHO allows the handover of the MS's services to be finished before the MS is actually disconnected from the old BS [18].

This paper reviews related strategies and management approaches used to achieve MEC handover that support the transition of service and application state information from one MEC node to another. MEC implementation use cases in a heterogeneous network environment are expanding and attracting the interest of researchers and industry. A standardized approach for MEC nodes to implement connected device handover exists.

This paper makes a contribution by providing a comprehensive review of the literature related to handover strategies for MEC. An overview of MEC and associated technologies is provided, and challenges to achieving an optimal handover strategy are identified. The main contributions of this paper are summarized as follows:

- Discuss the MEC handover strategies, enhanced architectures and use cases.
- Classifying the handover strategies that are effectively used in different research works based on the enhancement approach to accomplishing the handover.
- Compare handover strategies MEC hosts implement to migrate between MEC servers without interruptions or service deterioration.

TABLE 1. A list of commonly used acronyms in this paper.

Acronym	Definition
3GPP	3rd Generation Partnership Project
5G	Fifth Generation
ADMM	Alternating Directions Method of Multipliers
AP	Access Point
API	Application Programming Interface
APPs	Mobile Edge Applications
AQM	Active Queue Algorithm
ASPs	Application Service Provider
BER	Bit Error Rate
BS	Base Stations
ETSI	European Telecommunications Standards Institute
E2E	End to End
HHO	Hard Handover
IoT	Internet of Things
IP	Internet Protocol
MEC	Multi-Access Edge Computing
MEH	Mobile Edge Host
MEO	MEC Orchestrator
MEP	MEC Platform
MNs	Mobile Networks
MS	Mobile Station
M2M	Machine-to-Machine
NFV	Network Function Virtualization
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RNIS	Radio Network Information Service
RSS	Received Signal Strength
RSSI	Received Signal Strength Indicator
RTT	Round-Trip Time
SDN	Software Defined Networking
SHO	Soft Handover
SNR	Signal to Noise Ratio
S1	Signalling Application Protocol
UE	User Equipment
VANET	Vehicular Ad-Hoc Network
VHDL	Very High-Speed Integrated Circuit Hardware Description Language
VI	Virtualization Infrastructure
VIM	Virtualization Infrastructure Manager
VMs	Virtual Machines
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything

- Classifies the handover approaches based on the MEC and networking metrics used to determine the outcome of the handover decision process.
- Address the MEC handover challenges and the lack of a standardized MEC handover protocol that supports the heterogeneity of devices and networks.

The rest of the paper is organized as follows. Section II presents MEC background and related work to MEC handover and seamless handover strategies. Section III presents the ETSI MEC reference architecture, framework, MEC applications and use cases, and the state relocation approach. Section IV investigates the handover management strategies in MEC and the framework handover interface. Section V identifies selected handover management challenges for MEC-based and related applications. The conclusion is provided in section VI. The list of acronyms found in this paper is displayed in Table 1.

FIGURE 3. Multi-access edge computing network [1].

II. MEC BACKGROUND

An investigation of MEC was first initiated by Microsoft in 2009 and then launched by European Telecommunications Standards (ETSI) in December 2014. The development of MEC applications and capabilities is ongoing. The motivation behind proposing MEC as a promising Mobile Networks (MNs) communications technology was to provide end users with enhanced QoS and Quality of Experience (QoE) [7], [19].

Cisco [20] reported that in 2023, the number of devices connected to the Internet Protocol (IP) networks will be more than three times that of the population, and the connected IoT (home devices) will be around 40% of the 14.7 Million Machine to Machine (M2M) connections. Cisco also reported that the 5G transmission speed is expected to be 13 times higher than the average 4G mobile connection. Mobile cellular communications need to meet the massive growth in data usage and computational processing required by around 13.1 million devices by the end of 2023.

The MEC network example in Fig.3 illustrates a model network connecting end users, such as cars, real-time traffic monitoring, smart sensors, smart homes, etc. As shown in the example, devices offload information and tasks directly to the MEC servers, where computation and storage capacity are limited compared to the cloud. Information is processed and stored where computation and storage capacity are available, and thus, MEC is considered the best alternative solution to distant cloud services [1]. In this network scenario, MEC needs to decide when to relocate services; device mobility requires uninterrupted communication. Applications relocate the running session from the MEC server to an adjacent MEC server in the direction that the device is moving, and during the handover process, the application sessions run on two servers simultaneously. Relocation of any running session must share some session information in advance with the destination MEC server to accomplish the handover process without connection interruption or quality deterioration.

Recent research has focused on enhanced techniques and capabilities that can be added to the MEC architecture. New MEC architectures have been proposed with the integration of Software Defined Networking (SDN) and cloud-native virtualization techniques, called containers, which are implemented to enhance the management and orchestration of Mobile Edge Host (MEH). The intended architecture supports End to End (E2E) mobility required to guarantee persistent and uninterrupted services when mobile users move between different MEHs. In [21], Shah et al. introduces the integration of the SDN paradigm into an edge computing environment as an SDN-enhanced edge computing framework. The proposal supports inter-operator interactions for E2E mobility and QoS management [21]. SDN brings crucial functionalities such as availability, scalability, interoperability, resilience, and extensibility to the operation of MEC servers [22]. Another study also by Shah et al. in [23] introduces a distributed control plane architecture as an alternative architecture to the centralized plane for MEC-enabled vehicular networks to manage the MEC network handover for better network performance and mobility optimization.

Proposals studying MEC handover have considered a range of issues. From the decision-making strategies employed to ensure that running applications and services maintain continuity, to deploying network orchestrators with MEC servers. As discussed in [24] and [25], and as studied by Fondo-Ferreiro et al. in [9], respectively, the authors presented experimental work on migrating stateful applications between MEC servers. The work demonstrates how relocating a video processing application helps vehicle drivers recall the latest traffic signs. Another experimental work presented in [26] was studying handover for video streaming services in MEC by evaluating a system-level network emulator Simu5G integrated with an open network edge service software toolkit (OpenNESS).

Liao et al. [27] proposed a framework for learning-based channel selection to maximize the long-term throughput of the network subject to the long-term constraints of service reliability and energy budget in edge computing networks. An optimal handover strategy was proposed in [8] that considers the Vehicle-to-Infrastructure (V2I) connection Round-Trip Time (RTT) with a vehicle running a selected application. Doan et al. [28] presented a seamless service migration framework for autonomous driving in MEC environments. Doan et al. [29] proposed a programmable framework to minimize the cost of migration in MEC using a handover algorithm called Flexible and Low Latency State Transfer (FAST), which directly forwards states between source instance and destination instance based on SDN; a similar method is also discussed by Gember-Jacobson et al. in [30].

III. MEC ARCHITECTURE, FRAMEWORK AND APPLICATIONS

ETSI moved towards standardizing MEC in [32]. The latest ETSI MEC reference architecture is shown in Fig. 4. The MEC system comprises entities that are grouped into the

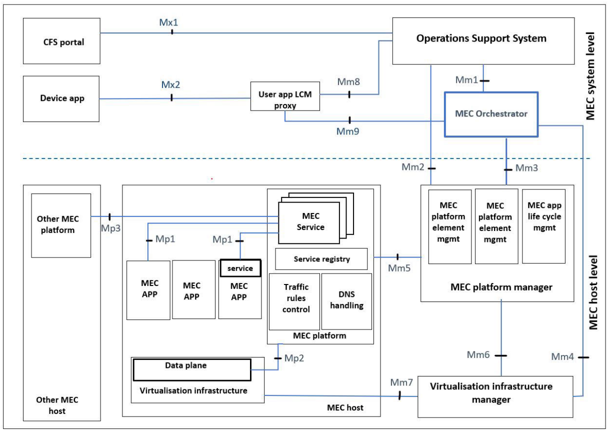

FIGURE 4. MEC reference architecture by ETSI [31].

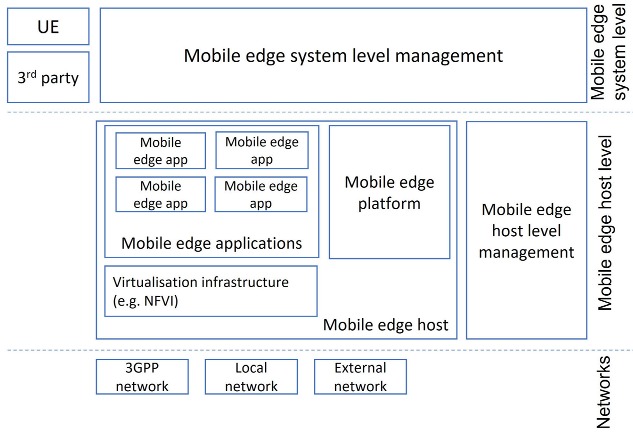

FIGURE 5. ETSI MEC framework [31].

MEC host level or the MEC management level and excludes the network level, as described in [31] and [33]:

- **MEC management level**. The entities required to support and run MEC applications within an operator network. The MEC Orchestrator (MEO) management or system level tasks is a system or management level entity that is responsible for selecting MEC hosts and applications based on their requirements, and manages policy requirements to guarantee the authenticity and integrity of hosts and running applications [5], [34].
- **MEC host level**. A Virtialization Infrastructure (VI) environment that hosts virtualized applications and services by providing network resources, storage, and computation, in addition to interfaces. The host level encapsulates the system core functions, as well as offering the VI capabilities of storage, computation, and network resources that facilitate Mobile Edge Applications (APPs). The host level consists of the following entities:
    1) **MEC Platform (MEP)**. Consists of the VI and other capabilities needed to host applications and services, manages application and service initiation and termination when needed, and provides an interface to the forwarding plane.
    2) **Virtualization Infrastructure Manager (VIM)**. Provides computation, storage and network infrastructure required to host applications and services. The VIM interacts with external cloud managers to perform a Virtual Machine (VM) handoff. MEC operation can be troubleshooted using information collected on performance and faults by the VIM and passed to the MEC management level [35].
    3) **Interfaces/applications**. The VI is used to host applications and services and other capabilities including the interfaces. Based on the MEC management instructions, applications and services are initiated on the VI, configured and validated [35].

The MEC reference framework in Fig. 5 describes the entities involved in the implementation of the VI-hosted applications and services [31]. The MEC framework entities are grouped into three levels: networking, system or management level and host level. The networking level provides network connectivity including with the RAN, core networks and cloud. The host level consists of the MEP, VI and supporting functionality [32], [34]. The ETSI framework facilitates edge applications and services that seamlessly and efficiently interact with MNs connected devices [33], [36]. MEC architecture, deployment in 5G and the migration from 4G to 5G explained deeply in [10], [37], and [38].

A. MEC APPLICATIONS AND SERVICES

Applications that can be hosted on MEC servers include gaming and multi-media to machine-type services such as Vehicle-to-Everything (V2X) and IoT [38]. Millions of mobile devices can be connected to MEC servers to benefit from edge computing and storage, gaining an advantage over cloud computing, specifically low latency, approaching 1 ms, and local data analysis and aggregation. Applications can be run in a virtualized environment, containerized application, or VM [1].

MEC ensures low latency access at the edge of the network in addition to more distributed approaches by locating multiple MEC servers at different geographic locations. However, distributing MEC servers in a wide range of areas with a diversity of computing resources might increase the complexity of network management. SDN can be used to simplify and centralize network management with intelligent real-time decision-making that enables transparent and seamless control of the network [23].

The study in [23] analyzes the centralized control plane and the distributed plane for SDN-based handover management in MEC. The distributed control management performed better than the centralized control plane architecture and provided more effective mobility management in dynamic, large-scale of MEC-enabled networks. Computational offloading, e.g., is one of the MEC capabilities that provides the edge devices (i.e., laptop, smartphone, smartwatch, etc.) the ability to transfer intensive computational tasks to an MEC server or

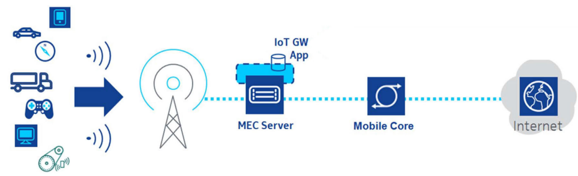

FIGURE 6. MEC as a gateway to IoT services [42].

MEC cluster. A range of offloading algorithms, such as ILP, COBSCN, MPOD, ELT-ENO, CaPC, COD, COA-GT, and JCORAMS, are presented in [1] and [39].

MEC provides a contextualized and personalized experience that cloud service subscribers can benefit from when using the real-time radio and network information [6]. The ETSI MEC was defined in 3rd Generation Partnership Project (3GPP) specifications and is now developing into a key component of modern networks. When the work on technologies that would become 5G was in the conception phase, MEC was deployed as an add-on to 4G networks. The learning outcomes found by adding MEC to 4G networks have improved development of MEC for 5G networks [22]. The integration of MEC, Network Function Virtualization (NFV), and SDN technologies is recognized as three key enablers for 5G network services [38], [40]. Consequently, MEC is a promising MEP for 5G network services and target environments not only to facilitate ultra-low latency but also to achieve task offloading, data analysis and aggregation at the network edge that is needed by future MNs [23], [38].

The MEC architecture addresses the bandwidth and latency challenges for IoT and other applications, such as video analytics, location services, data caching, and augmented reality, discussed in [41]. ETSI identified MEC as an essential enabler for real-time operations required by IoT services and applications [2]. MEC's distributed control plane architecture can facilitate IoT device mobility and support IoT mission-critical use cases that require a high reliability of 99.99% and a latency of 1 ms [2].

IoT devices with limited resources can utilize MEC resources to achieve outcomes that benefit from MEC's enhanced computational and data storage capabilities. MEC servers, as illustrated in Fig.6, can serve IoT applications by acting as low latency aggregation points or a gateway that can analyze and aggregate the IoT service traffic before the traffic is sent to the core network [2], [33], [42]. At the edge, handover is a necessary procedure that must ensure service continuity and latency reduction be achieved [6], [43].

B. STATE RELOCATION IN MEC

One of the core functions of the MEO is to trigger application initiation and termination, and to relocate the application when needed. MEO selects the targeted MEC host(s) based on the latency and the available resources and services to initiate applications in the MEC environment, as discussed in [31]. Hence, designing the orchestration framework should consider managing the mobility of devices running a real time session [6].

Timing plays a primary role in delay-sensitive applications. Live migration of a running session to another server without interruption or disconnecting users is the process used to handover tasks between the edge nodes. Available solutions that cloud services rely on include the Docker migration service, a containerization platform that controls container services rather than traditional VMs, as discussed in [44] and [45].

The MEO, the MEC system manager, is responsible for the application or state relocation within the system. Relocating an application or a state must first guarantee service continuity, and this is achieved by checking and ensuring that network connectivity exists between the two MEC hosts and by preserving the MEC application instance after the relocation is completed [46].

The network topology and deployment options are key elements considered when the MEC host implements handover. The relocation of a running application from one MEC server to another has been proposed and tested using a variety of approaches. MEC supports application state relocation, as defined by ETSI, which is when the User Equipment (UE) location changes in the network, the chance of latency might increase between the MEC application, hosts, cloud, and other systems, which could cause sessions to deteriorate.

Connectivity is impacted by network congestion and the physical distance between the UE and the target MEC host. Thus, MEC applications can continue serving UE even with location changes in the MNs. The relocation decision is usually made to satisfy latency and resource availability requirements when the moving UE is associated with another MEC host that is more appropriate for application and service performance. The source and target MEC hosts interact with each other to move the application state from one instance to the target, and currently there is no standardized mechanism for this to occur, so the process relies on the application design [31], [32].

Application relocation in MEC is initiated when a Radio Network Information Service (RNIS) notification is received by the MEC system. The serving cell is changing due to user mobility [37], [46]. The application relocation occurs to ensure that when the end user context moves to a new cell, the MEC application instance has already moved and is ready to be used. MEC maintains data structures by creating an application context whenever a new MEC application is initiated. ETSI in [37] stated that application relocation is initiated for different purposes. Addressing a resource shortage, as shown in Fig. 7, is one case where the MEC application is relocated due to a resource shortage in the virtualized environment [46].

The other scenario involves user mobility, as shown in Fig. 8, where changes in access technology (e.g., Wi-Fi to 5G) or transitions between different access technologies result in vertical or horizontal handovers [46].

One of the typical examples of the state session is the web session object; Microsoft identifies the session object as being able to store user preferences and other parameters;

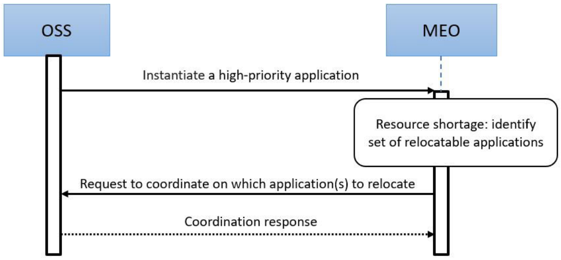

FIGURE 7. Application relocation due to resource shortage [46].

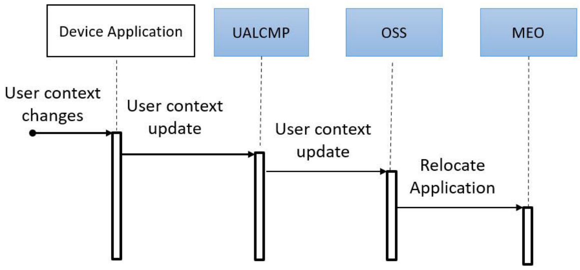

FIGURE 8. Handling user mobility [46].

it saves information about a specific user session on a target device, for instance, when the user moves between pages in a certain application, user information is stored in the session object until the user session is abandoned or expires. A good example is a web browser session that maintains the session state in browsers that support cookies [47]. Similarly, in MEC applications, the state session of the MEC application is transferred between MEC hosts to serve the UE efficiently.

A key challenge of state migration in MEC is to reduce the total cost of the state transfer due to resource limitations. According to Doan et al. [29], minimizing the latency to significantly reduce the service disruption and meeting four crucial MEC requirements: high availability, programmability, latency, and flexibility [7], [29] are key challenges in MEC state management. Doan et al. [28] proposed a live seamless service migration framework for the autonomous driving system for testing the effect of MEC on a seamless migration for the autonomous driving system by comparing a central cloud scenario with an MEC scenario where MEC was able to handle and solve the latency issues for live service migration.

The state relocation approach closely contrasts the handover management process in MEC. The state relocation primarily encompasses the strategies employed to migrate to the computational state, while the handover mainly describes the seamless transfer of the whole connection session. Fig. 9 explains the general state relocation approach. The service migrates from the source MEH to the target MEH, migrated in a successful sequence of events denoted as A and B in the illustration. There are three triggers for the service migration: by the MEO, the MEC application at the UE, or by the RNIS at one of the MEHs (source/target MEHs). The MEO plays a significant role in MEC services migration; it is responsible for selecting the target MEC host(s) and taking the migration decision when needed, as shown in Fig. 9 [48], [49], [50].

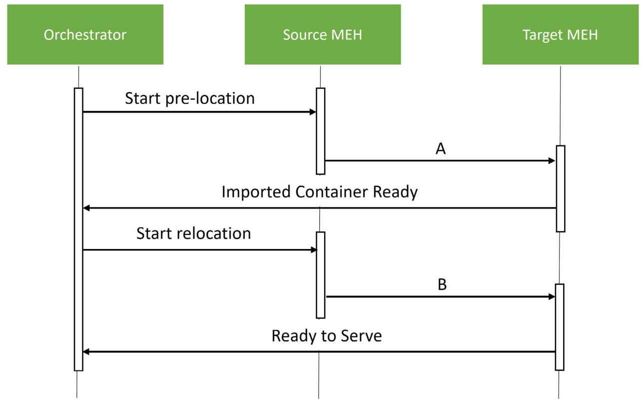

FIGURE 9. State relocation approach [48].

IV. MEC HANDOVER CONTROL

A seamless handover is achieved in a wireless network by utilizing a sequence of predetermined actions. Before the handover takes place, there is a network discovery phase, where the connected MEC server collects information from adjacent servers to identify the best-matched server that fulfills the UE QoS and QoE requirements. The handover process can highly affect the QoE for the end user. MEC has to maintain QoE to improve the overall network performance. QoS is the measurement of the overall performance of a service. In edge computing, QoE refers to the qualitative assessment of an end user towards a specific service, as defined in [51], [52], and [53]. In other words, finding a server that can become the new host of the UE as it moves across a network while maintaining QoS and QoE requirements and ensuring service continuity. The decision phase is next, known as the initiation phase; the handover commences after deciding that there is a need to shift the UE to the selected destination MEC server [17], [18].

To improve handover, it is essential to identify the scenarios that lead to handover commencing. In wireless communication networks, handover is classified based on the following factors: access technology, protocol layers, and UE. Access technology handover is divided into two types. Horizontal handover, also known as an intra-technology handover, is the handover between similar network technologies, e.g., 4G to 4G, in a homogeneous system. A vertical handover, also known as an inter-technology handover, is a handover between different network technologies, e.g., 3G to 4G, which requires two network layers to interact (layer 2 Data link and layer 3 Network layer) for a successful handover procedure. Protocol layer handover is the type of handover related to a specific layer involved in the handover process, whether it is a cross layer-based, network layer-based, or data link layer-based handover. The most common handover classification is the type of technology supported by the network, which is mainly divided into HHO and SHO [17], [18]. The initiation of the handover process differs for each type, besides the network measurements and requirements to consider when making the handover decision, as discussed earlier.

MEC servers manage seamless application handover based on end user mobility without compromising QoE or MEC service. Fig. 10 presents a load awareness scheme in SDN-based MEC to facilitate a seamless application handover between MEC servers. An SDN-based MEC environment enhances the operation of edge networks and assists MEC servers to improve performance. The SDN-based MEC environment is an architecture that separates the data plane and forwarding plane of network devices, and this can include the operation of the network layer in MEC servers. The programmability aspect of SDN allows MEC to conceal the complexity of the heterogeneous edge network from the end users, thus simplifying network configuration and policy implementation. Deploying an SDN-based MEC environment enhances the ability of terminal devices' switching between network Access Points (APs) [54], [55].

Improving QoE is a motivating factor for MEC. One of the main challenges of MEC use cases is controlling the handover process during device mobility. Handover control is the strategy used between edge servers before, during, and after the handover process. Specific measurements are used to evaluate a system's optimal handover performance. Defining optimality, however, can differ from one system to another based on the use cases in that system [8].

In 5G systems, for example, controlling applications' handover is one of the obstacles to achieving novel services, besides offering services and applications with ultra-low latency, ultrahigh reliability, availability, and high data rates [11]. In an IoT heterogeneous environment, the handover occurs between APs or cloud servers [6]. Mobility and continuity demand intentions in the MEC environment because of their high impact on MEC services of resource allocation, computing offloading, and service orchestration [34].

Handover performance can be evaluated based on common metrics used to evaluate network performance, e.g., delay, RTT, Signal to Noise Ratio (SNR), network coverage, and power consumption in some cases [8], [17]. The service interruption time is an additional metric used in handover schemes; it is the duration between the transmission suspension time to the transmission resumption time, determined by the Received Signal Strength Indicator (RSSI) measurement and the completion of the handover procedure [18]. Research efforts to improve handover strategies and techniques to better support mobility and service continuity are ongoing. Table 2 lists selected handover approaches and the algorithms used to improve the network performance and classifies the approaches according to the effectiveness of the strategies employed based on common network metrics, including delay, RSS, packet loss, and mobility.

In [8], a series of experiments were carried out to identify an optimal handover procedure by proposing a strategy based on two elements, the MEC server selection and timing, to make the handover decision between edge servers. Eijnden in [8] separated the MEC handover process into two categories: handover of the MEC server application state, also called data handover, and radio handover. The research identified an approach to re-evaluate handover optimality for every handover procedure carried out. This approach aims to determine the instantaneous optimal handover strategy [56].

ETSI defined a RNIS to support MEC by providing authorized applications with up-to-date radio network information related to radio network conditions [32]. An optimization model for managing mobility procedures using RNIS from an AP with the Signaling Application Protocol (S1) was proposed in [57]. The research identified the MEC applications, MEP, and RNIS that exchange information to optimize service performance. Exchanged information includes handover states to verify behaviors among source and target nodes in the network. RNIS sends handover procedure notifications, including handover execution and completion, handover preparation and cancellation, and handover failure; the model is used to optimize the mobility requirements needed to ensure service continuity [34], [57].

MEC servers require two strategies to consider optimal handover according to [57]: the selection of the ideal destination MEC server, and the best time to make the handover decision. In each handover process, the optimality of the current and potential destination MEC servers is re-evaluated. The author presented several suggestions to manage the handover without determining the optimal strategy for MEC handover.

Another proposal in [58] presents a framework that splits the MEC architecture into three layers, the base layer, the application layer, and the instance layer, where each layer contains the guest OS and kernel, the idle version of the application, application-specific data, and the running state of the application, respectively. Every MEC server has a copy of the base layer, and thus there would be no need to transmit it during a handover event. The application layer runs applications, and a copy of every MEC supported application is pre-installed. The instance is always transmitted during a handover. Hosted applications and services could be transferred, no matter the status of the application, and the instance data transmitted to the destination MEC server after the application instance is suspended, and before the destination server application layer initiates the application. This approach could improve handover performance for specific applications by limiting the transferred data [8], [58].

Al-Badarneh et al. in [59] presented a software-defined edge computing approach for V2I and V2V to enable communications with reduced latency and high bandwidth by utilizing an MEC search strategy for V2I and utilizing caching at vehicle-level for V2V peers. The strategy proposed in [8] uses RTT detected by the vehicle and the physical distance from the server as the main metrics to measure the connection quality and handover trigger. The work considered a delay-hysteresis strategy as the optimal handover strategy for V2I communication.

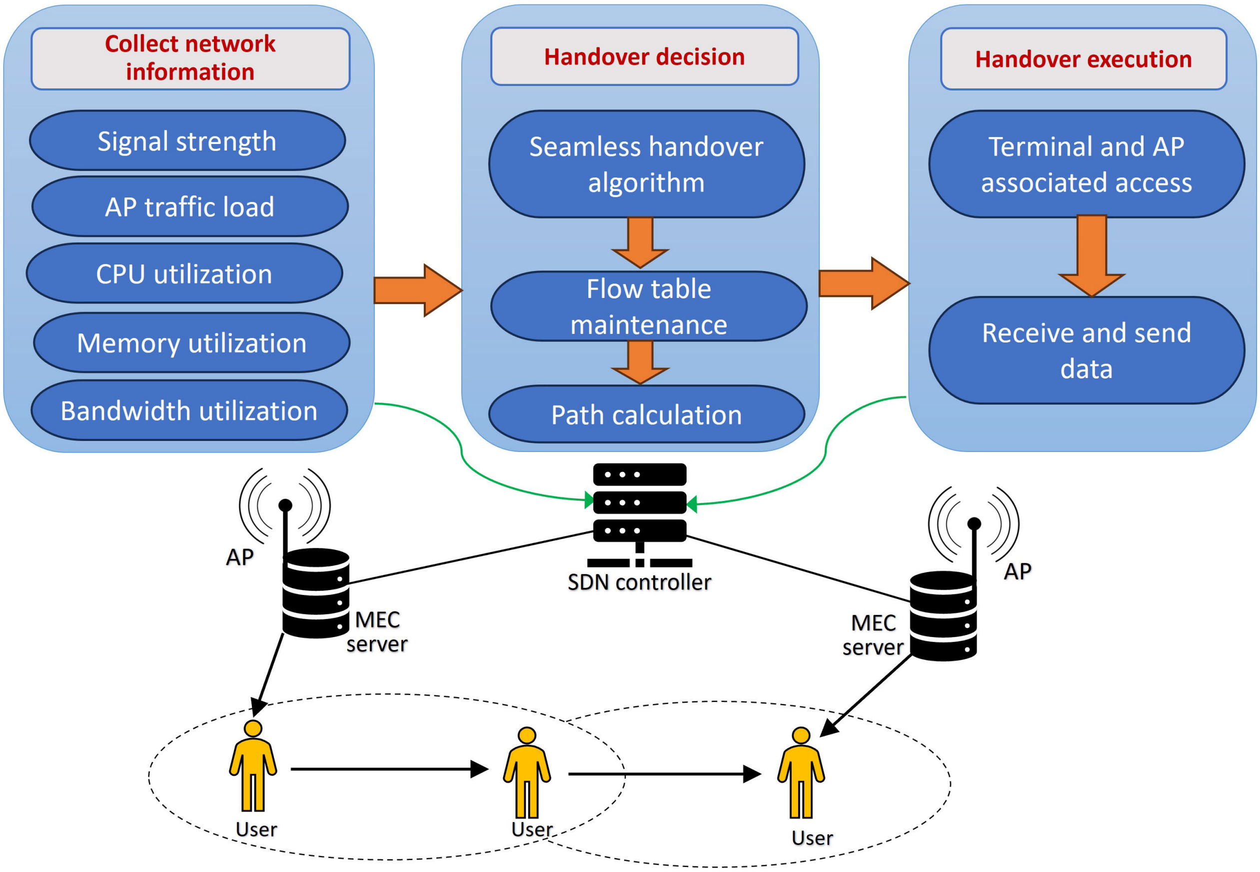

FIGURE 10. Seamless handover control in SDN-based MEC environment [54].

SDN is proposed as a system that can be used to manage the MEC handover process in vehicle mobility [23]. The proposed architecture divides the large-scale networks into SDN-based domains to manage service mobility requests and vehicle handover by exchanging network state information between distributed controllers in each domain. A series of experimental works carried out in [8] suggests that the physical distance-metric strategy recommends starting handover when resource overload occurs in an MEC server. The work proposes an approach that significantly reduces the RTT time for achieving an optimal handover using delay-hysteresis, a decision-making strategy that looks for an alternate MEC server with at least 15% more resources available than the current server.

V. HANDOVER CHALLENGES IN MEC

Handover failure is one of the inherent issues with wireless networks due to interference, mobility, packet loss, memory space, traffic flow, channel bandwidth, and other factors [40]. Networks with MEC deployed are still considered advanced and more complex than networks that rely upon centralized clouds [64]. However, controlling handover may vary in MEC systems for several reasons, such as application types, system requirements, or the overall compatibility of deployed MEC servers.

One of the key MEC capabilities is to provide end users with a better QoE by ensuring low latency communication, improved flexibility, agility, and virtualization usage [7]. Selected MEC handover challenges in Table 3 compared to address the challenges in different works, along with their impacts on the network and some suggested solutions. They are classified as follows:

A. MOBILITY, MIGRATION AND SYNCHRONIZATION

Mobility is a cause for service disconnection during handover between edge servers. Application service quality can degrade when the connection between UE and MEC server is affected by reduced bandwidth, increased delay or jitter, and other factors [65]. The state of the network during handover can cause network load imbalance and, in some cases, a decline in QoS [54], [60].

To optimize the migration process and to avoid service interruption during the handover, the source and destination servers should synchronize to minimize the time taken for the handover to occur; the procedure requires exchanging information ahead of time [66]. For a complete integration of IoT services, Shah and Yaqoob in [67] addressed this to show the importance of having a management service for data aggregation during mobility [67], [68].

TABLE 2. Comparison of handover strategies approaches.

Scheme	Ref.	Strategy	Contribution	Results	Performance Evaluation Metrics			
					Delay	RSS	Packet Loss	Mobility Management
Load awareness and buffering	[54]	Seamless handover based on load awareness	-Using wireless AP perception - Algorithms to select APs with highest weight	- Reduced frequent handover, network load, delay, cost and consumption - Improved throughput and network imbalance	✓	-	✓	✓
	[60]	Two Network-based handover mechanisms	- Pre-handover and buffer scheme - SDN-based defined solution	Reduced packet loss and handover latency	✓	✓	-	-
Threshold	[8]	Delay-hysteresis strategy	- 4-Triggers used to evaluate handover based on delay and distance - Handover whenever alternative with 15% better is available	Significant less RTT percentage	✓	-	-	-
	[11]	Threshold handover scheme	Calculates three threshold levels of RSS	64% better handover quality from the traditional handover	-	✓	✓	-
Location optimization	[56]	Gateways location optimization algorithm and Active Queue Algorithm (AQM) algorithm	- Selecting gateways based on importance and given targets - Keeping buffers short enough	Both algorithms minimize E2E latency	✓	-	-	-
	[57], [61]	Deploying RNIS in mobile edge networks	Up to-date handover notification for mapping RNIS Application Programming Interface (API) onto S1 application protocol	- A usable model in based on up-to-date radio information - Used to optimize mobility and service continuity	-	✓	-	✓
Searching Algorithms	[59]	MEC server searching algorithm	Utilizing cooperative MEC search strategy to support mobility for V2I and Vehicle-to-Vehicle (V2V)	Minimal latency with high bandwidth	✓	✓	-	✓
QoS	[14]	Handover decision making approach	- Collecting handover information using Very High-Speed Integrated Circuit Hardware Description (VHDL) language to facilitate handover decision making	- Maintains QoS parameters when handover - Applicable to other MNs - Selecting optimal path for handover	-	-	-	✓
	[59]	Vehicle-level caching technique	- Utilizing V2V instantaneous communication - Compare latency at the core cloud and the network edge	Better QoS and high service availability	✓	-	-	-
	[62]	MEC handover authentication scheme	- Supports MEC handover authentication - Supports inter-domain and intra-domain handover	- Robust security protections - Congestion avoidance - Reduced computational and communication overhead	✓	-	✓	-
Framework or architecture	[23]	New distributed control plane architecture	- Leverages multiple SDNs controllers - Collect network-wide information in real time	Effective mobility in dynamic and large MEC environment	-	-	-	✓
Timing and scheduling	[44]	Seamless handover timing scheme	- Pre-migration computations when handover is expected - Handles consecutive handovers in a short time	- Latency reduction - Recovers missing jobs during handover	✓	-	✓	-
	[63]	- Service scheduling approach - Inter-cell handover mechanism	- Controlling traffic forwarding - Service scheduling to control traffic and execute tasks	- Enhanced MEC mobility management - Reduced latency cost, and congestion	✓	-	✓	✓
Forwarding and switching	[15]	Four soft-handover solutions	- Switching enhancement of edge gateways by adding 1-byte to sequence field - Using overlaps links to connect AP's	- Ensured lossless and in-sequence delivery of data - Seamless SHO - Applicable to other network systems	✓	-	✓	✓
	[25]	MEC-SDN redirection approach	- Relies on SDN to redirect traffic	- Reduced latency and throughput impairments - Compatible with large populations	✓	-	-	✓
	[45]	Application-driven handover (ADHO) strategy	Open radio resources for 3rd party applications to apply handover policy	Using and optimizing the limited radio resources management efficiently	-	-	-	✓

Checkmark (✓): Used to indicate that the strategy has contributed to enhancing a parameter. Hyphen (-): Used to indicate that there is no change in the parameter.

Mobility management includes operations that MEC servers need to complete successfully, such as arranging a BS channel for a scenario where the MEC server is integrated with a BS, initiating handoff, and breaking the connection from the previously connected BS [8]. The effect of the traffic flow and the mobility prediction can contribute to the handover functionality [8]. Seamless handover experiments performed in [11] found that high mobility and QoE are a major challenge for Vehicle Ad-Hoc Networks (VANETs) and thus require handover strategies with improved algorithms to overcome the UE overlapping at a crossroad [11], [69]. To address this process, Fig. 11 shows that when player1 is moved from the connected MEC server to another MEC server host, where the running task is migrated to the target MEC host with a new AP, The migration here, caused by the UE mobility migrates only running task MEC servers, maintaining the QoE of the end user without the need for the centralized data center to contribute, and usually occurs within the network to manage the task migration due to mobility [70], [71].

B. SECURITY AND QUALITY OF SERVICE

For seamless handover, reliability, QoS, and security are all dependencies; handling the three requirements is a significant

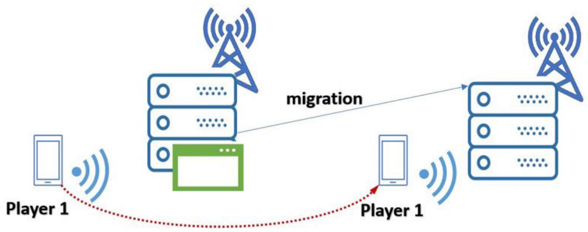

FIGURE 11. Task offloaded and migration [71].

challenge for handover management [69]. Monir et al. in [11] experimentally identified how application QoS was influenced by the timing of the handover process. Three threshold levels of the RSS were tested using MEC servers to find the best-received quality after a complete handover process. The study recommended adding more metrics to the handover analysis and algorithm schemes to achieve better outcomes when the handover is performed. In other use cases, the evolution of various communication technologies and applications requires additional network bandwidth and computing resources to ensure uninterrupted QoS and reduced latency [54], [60].

Another study discussed in [14] the need for new routing algorithms that supported MEC handover whilst maintaining connection QoS, in addition to the need for a handover protocol to support different mobile terminals. In [41] and [72] data security during handover is identified as a challenge.

C. ENERGY CONSUMPTION

In [54] the authors identified that high energy consumption of the MEC server whilst completing tasks and during task management activities, including commissioning and decommissioning, remain challenges.

Limited energy and computing capacity remain open concerns in IoT applications, and the inefficiency translates into MEC-enabled IoT environments, according to the authors of [64]. Zhou et al. in [73] proposed an energy consumption algorithm for in-vehicle UE such as smartphones and IoT devices) to enhance energy-efficient workload offloading for UE. A less-complex distributed solution was proposed based on the consensus Alternating Directions Method of Multipliers (ADMM) with higher scalability, less signaling overhead, and better flexibility compared to the common centralized approach.

D. HETEROGENEITY AND SCALABILITY

System scalability is the ability to ensure service availability regardless of how many edge network devices are in use. All edge devices should access edge applications simultaneously to avoid service interruption [41], [65]. Service migration during the handover must be achieved without affecting the end user QoE; a scenario is illustrated in Fig. 12 where the end user moves from one BS to another, the entire service with its resources migrate to the associated MEC host with new BS. This is usually implemented by the ASPs to manage the network resources (load balancing between MEC servers) or to reduce latency to optimize the network performance and availability. In a scenario where the user moves between different networks under the mentioned circumstances, The ASP decides to migrate partial or complete resources to maintain the seamless migration between heterogeneous MEC hosts [70], [71].

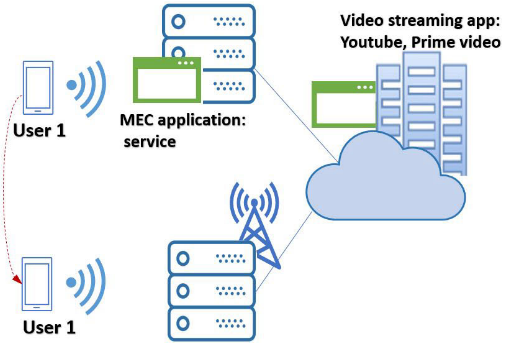

FIGURE 12. Service migration in MEC [71].

Deploying applications platforms, including MEP, that use different access technologies such as Wi-Fi, Wi-Max, 5G, 4G, 3G, and other spectra, no matter the number of active subscribers using them, it should be functioning continuously and performing a smooth handover between edge points or MEC servers [41], [74]. One research proposed a Follow-me fog framework to ensure uninterrupted services during the handover process in [44]. Also 5G uses the MEC-based environment counts some handover challenges of service migration, in addition to handling resource allocation, as discussed in [75]. As 5G supports heterogeneous interface frameworks, the need for utilized handover techniques and new interference is one of its standing features to ensure service continuity [4], [76], [77].

E. LACK OF STANDARDIZED HANDOVER PROTOCOL

Existing research has identified and resolved handover and state relocation problems for application sessions between MEC servers. There are various methods to manage migrating applications between edge clouds efficiently and with minimal cost. Despite this, no existing or previous study has identified a protocol to manage the handover process between MEC servers that can support numerous end users or devices connected to the edge network. Accordingly, we suggest modeling a handover protocol that manages the session relocation process between one or more connected edge servers as a research gap. ETSI in [41] highlighted the need for a standardized protocol to manage the MEC handover process, as MEC is a recent technology in the testing and implementation phases.

Another research gap is the need for improved handover management. There is a need for more studies and experimental work to analyze and identify the handover management load and what constitutes a threshold prompting a handover requirement in an MEC-based network.

TABLE 3. Comparison of common handover challenges in MEC.

Ref.	Challenges	Description	Impact	Solution
[8], [11], [54], [60], [66]	Mobility and synchronization	Maintaining QoS during mobility to avoid any service disconnection during handover between edge servers, managing dynamic network conditions and UE mobility pattern	Affecting QoS, network load imbalances	Synchronization mechanisms and improved algorithms to overcome the UE overlapping at a crossroad
[65], [67]–[70]	Mobility and migration	High mobility, services migration and synchronization during handover between source and destination servers to minimize the handover time, maintain continuity, involving state transfer, session persistence, and real time data synchronization	Service degradation, network load imbalance	Efficient IoT data management
[11], [14]	Security and QoS	Challenges associated with ensuring reliability, QoS and security during the handover, addressing vulnerabilities during handover transitions, ensuring data integrity and privacy, and adapting QoS dynamically based on varying network conditions and security requirements.	Influences application QoS, requires new routing algorithms	Dynamic Qos adaption mechanisms to ensure uninterrupted Qos
[41], [72]	Security and QoS	Encompassing the reliability, QoS and MEC security aspects as QoS is highly affected by handover timing	Influences application QoS, requires new routing algorithms	Handover protocols to handle heterogeneous mobile terminals, data security measures
[41], [44], [75]	Heterogeneity and Scalability	Challenges arising from ensuring uninterrupted services and managing resource allocation complexity, scalability of MEC systems and managing heterogeneity of edge devices, including challenges of interoperability, and resource management in diverse environments	Service interruption, resource allocation complexity	The use of frameworks like the Follow-me fog framework that ensures uninterrupted services during handover
[4], [65], [76], [77]	Heterogeneity and Scalability	MEC systems scalability and edge devices heterogeneity, and maintaining service quality across scales during handover without affecting the end user QoE	Service interruption, resource allocation complexity	Strategies for handling interference in heterogeneous environments
[54], [64]	Energy Consumption	High energy consumption of MEC servers during task management, Critical need for energy-efficient operations in MEC servers, especially for intense computation and data processing tasks; importance of optimizing energy usage	High energy inefficiency and environmental sustainability concerns	Energy-efficient algorithms
[73]	Energy Consumption	The imperative for efficient energy management, and imperative for efficient energy management by focusing on computational efficiency and reduced energy usage under high-load conditions	Computing capacity limitations	Less-complex distributed solutions based on ADMM

VI. CONCLUSION

MEC deployments overcome the challenges of supporting new applications that require ultra-low latency and the increasing need for task offloading by UE, particularly IoT devices and vehicular networking. Improvements to QoS and QoE are key motivators for MEC development and ongoing research. Successful handover that is reliable and efficient and ensures service continuity is a major requirement for MEC.

This paper discussed the ETSI-MEC reference architecture and framework and described current research and proposals for handover techniques that provide enhanced mobility and state relocation. Challenges and research gaps have been identified, particularly with a focus on handover. This comprehensive review has identified state relocation approaches and presented MEC handover management strategies that have been recently proposed in the literature.

As identified by ETSI, MEC is a significant enabler for the evolution of 5G and IoT applications. The implementation of MEC within a mobile and IoT environment requires a robust handover management solution. The remaining work to be carried out is to identify a robust handover protocol and for handover management to be improved while reducing energy utilization.

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