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Review article

An overview of mobility awareness with mobile edge computing over 6G network: Challenges and future research directions

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ABSTRACT

The evolution of science has given rise to many technologies that have changed the world. The upcoming Six-Generation (6G) mobile network indicates a fundamental transformation in wireless technologies, enhancing connectivity and data transmission rates. In this circumstance, Mobile Edge Computing (MEC) is a paradigm technology that emerges as a key major supporter of enhancing mobility awareness. Edge computing offers improved efficiency for service migration from the edge node to the user. However, mobility management in MEC is a complex challenge as seamless handovers between edge nodes must be efficiently executed to ensure uninterrupted service for mobile devices, demanding intricate coordination and low-latency decision-making. To the best of the author's knowledge, there has been no comprehensive work on the most recent developments in mobility awareness using mobile edge computing in 6G. However, this paper aims to present a general overview of the intersection between mobility awareness and MEC over 6G networks. The general concept of MEC in 6G mobile networks is comprehensively introduced. This will highlight the integration between MEC and 6G for bringing more efficient network and service migration to the edge, reducing latency, and enhancing the user experience. Meanwhile, this survey discusses augmented reality with MEC applications. This survey discusses the integration of mobility awareness and mobile edge computing in upcoming mobile applications and emphasizes the need for 6G networks. This integration results in providing seamless communication during handovers between the serving base station and the target base station. This study contributes to understanding the upcoming trends that will enable the operation of mobility awareness and MEC operation in the 6G mobile communication. Furthermore, we delve into a comprehensive overview of the challenges and future research directions for mobility management with MEC in 6G mobile networks, underlining the complexities and potentials of integrating mobility awareness and mobile edge computing.

1. Introduction

The exponential increase in mobile network devices and sophisticated applications has significantly increased data traffic communications [1]. According to an Ericsson report released in June 2023, there will be about 9.1 billion mobile subscriptions worldwide in 2028. Furthermore, approximately 88 percent of the overall subscriber base is anticipated to utilize broadband mobile connectivity [2,3]. Internet access will enable the interconnection of numerous mobile gadgets and household equipment, enabling the development of new applications and smart homes. For this reason, data traffic on mobile devices will increase with advanced technologies in the next ten years. Therefore, the spectrum requires a sufficient bandwidth (e.g., 3 GHz) to use cases of wide area to enable advanced, extended reality and holographic

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communications over a 6G mobile network [4,5]. As the study on Fifth-Generation (5G) technology progresses toward achieving a worldwide standard, the scholarly community has begun directing their attention toward the advancement of solutions that go beyond 5G and pertain to the 2030 age, commonly referred to as 6G [6]. The potential of 6G and Mobile Edge Computing (MEC) to revolutionize the telecommunications industry is truly inspiring. Different innovative projects for the mobile communications network of the future have been implemented. A research team vision named Future Technology Trends of Terrestrial for International Mobile Telecommunications (IMT) systems with the International Telecommunication Union (ITU-T) was initiated in October 2020 [7,8]. The research team aims to investigate the potential of networks in the future [9], specifically in 2030 and even further. Next-generation networks are anticipated to facilitate innovative challenges during this period, including holographic-type communication, ubiquitous intelligence, Machine-to-Machine (M2M), and multi-sense experience [10]. In the interim, the Third Generation Partnership Project (3GPP) will persist in advancing the development of 5G technology towards 5G Advanced, alternatively referred to as beyond 5G. This transition from 5G to 5G Advanced is a crucial step in the evolution towards 6G, as it sets the foundation for the advanced capabilities and features that will be further enhanced in 6G.

Additionally, it is anticipated that the standardization of 6G technology will commence in Release 20, approximately during the latter half of 2025. Subsequently, the technology proposal will be prepared for evaluation by the International Telecommunication Union-Radiocommunication sector (ITU-R) and Huawei around late 2028 and early 2029. The ultimate objective is to finalize the specifications of International Mobile Telecommunications-2030 (IMT-2030) by 2030 [11]. In the forthcoming era, 6G networks are poised to usher in a new era of technical advancements, offering immersive, omnipresent, and sensory digital experiences. When these advancements are implemented on a large scale, 6G applications could revolutionize our lifestyles. The internet of senses, in particular, can significantly reduce the necessity of physical travel for employment, leisure, education, or healthcare. This could substantially reduce greenhouse gas emissions, a crucial step towards a more sustainable future that should motivate us all to support these technological advancements. 6G promises to revolutionize different applications, such as Augmented Reality (AR), by offering faster speeds and greater data capacity, enabling more immersive and interactive experiences. Future mobile networks must deliver high transmission rates, high dependability, mobility, and low latency to efficiently provide Internet of Thing (IoT) services such as AR and telemedicine systems for mobile devices, vastly increasing the initial goals of 5G networks [12]. Furthermore, the MEC capacity is limited to the User Equipment (UE), so it is necessary to provide the characteristics of latency and reliability for mobile systems, allowing more users to communicate.

MEC framework is a novel computing paradigm that facilitates the emergence of new vertical business sectors, such as the IoT and AR. This paradigm aims to relocate computational processes and data storage closer to the edge network, precisely Wi-Fi access points and wiring closet switches situated between end-users and server clouds. The objective is to minimize latency, guarantee optimal network functionality and service provision, and enhance user experience [13]. 5G enables mobile networks to support various industry applications, health care, and education. It provides consumers with advanced capabilities to access services on their mobile devices with minimal delay, regardless of location [14]. However, Edge Computing in Context Awareness comes from the increasing importance of MEC in technology. MEC is recognized as a pivotal technology that significantly enhances mobility awareness and offers various benefits, such as low latency, location awareness, and mobility assistance, which address the limitations of traditional edge computing. The paper aims to review and analyze the existing research efforts in context-aware approaches for edge cloud computing, highlighting the advantages and disadvantages of these techniques. By exploring practical and applicable context-aware methods and considering future directions and challenges, the study seeks to contribute to developing new and effective context-aware solutions in MEC, with the potential to impact the field significantly [15]. Mobility awareness causes substantial challenges to the reliability of applications in operation due to highly changeable network circumstances, platform and protocol variety, and related heterogeneity. The operating circumstances of MEC services may also be affected by the pattern and velocity of UE movement. Therefore, it is essential to consider mobility in MEC to guarantee the expected QoS for active applications and a satisfying Quality of Experience (QoE) for the end user. Because of its intended use in supporting multiple access networks, MEC design necessitates intricate processes at both the system and host levels for operating and managing its numerous features. There is a substantial opportunity to boost overall performance by designing solutions that can adapt to the movement of user mobility.

With MEC, users can execute a variety of 6G apps that necessitate high computing capabilities and low latency performance on an edge server, freeing up resources on the central server for other tasks. MEC is an appropriate solution for reducing computational latency in AR. It can efficiently handle the offloading technique of AR tasks to the nearest Base Station (BS) to the user. Future innovations in AR apply to 5G wireless communication and can be more potent on 6G networks. Nevertheless, implementing MEC has incorporated standardized storage to offer an advantage in network performance. It is imperative to establish an efficient offloading method to enhance the latency and dependability of MEC for AR applications. This work aims to examine the computational aspect in a contemporary or remote manner. Due to this rationale, reducing data from the cloud to Edge Nodes (ENs) and partially processing the transmission to minimize latency is a potent approach.

However, several obstacles make creating mobility-aware solutions for MEC far from easy. This challenge is used to maintain low communication latency and provide high bandwidth. This survey will assist in evaluating 6G systems to integrate more user mobility applications. Within the factor, mobility awareness is an issue in wireless networks that affects the performance of the Handover (HO) algorithm. This field's challenges and future research directions highlight the need for continuous innovation and improvement [16,17].

Although there has been little research on this topic, no prior study has undertaken a complete overview of the latest advancements in mobility awareness with mobile edge computing in 6G. Integrating MEC and new technology in the 6G era presents a transformative approach to enhancing network performance through adaptive control for energy efficiency and low-latency communication. However, MEC has a knowledge gap regarding AI-enabled 6G communication requirements and technologies. Also, the challenges related to service mobility, such as seamless handover and resource allocation, need further exploration and optimization of task offloading and minimizing latency. Future research should urgently focus on innovative technologies to enhance network performance. This article thoroughly examines recent advancements in mobility awareness and mobile edge computing, aiming to improve the existing studies. It offers a.

Complete overview of the conditions for implementing new-generation technologies introduced in 6G and MEC applications, highlighting the pressing need for further research.

The contributions of this paper can be summarized as follows.

- Discussing mobile edge computing in 6G, enabling emerging technologies: The excessive growth of new applications has more benefits for exploring 6G technologies. The efficient network and computing capacity improve the user's reliability and reduce the deployment cost. Some potential 6 G and MEC applications include smart cities, autonomous vehicles, remote surgery, and immersive gaming. These applications leverage the high velocity, low latency, and high-reliability capabilities of 6 G and the distributed computing power

of MEC to deliver innovative and transformative experiences. Discuss mobility awareness in MEC applications and highlight the benefits of service migration for users.
- This study comprehensively explains the relevant investigations to demonstrate the use of AR applications and their relations to MEC and mobility awareness suggested in the existing literature. Every accessible study is effectively condensed. This summary encompasses the rationale behind the investigation, the proposed resolution, the application employed, the objective obtained, and identified limitations.
- The related study reviews existing survey papers and articles and enhances the utility of mobility awareness with mobile edge computing. It discusses mobility awareness's contribution, advantages, and disadvantages with its applications.
- Research challenges and future directions are extensively discussed in this survey for the new generation of technology.

This paper outlines the following sections: Section II presents a research background of mobility awareness and mobile edge computing, which enables user mobility to connect to different applications. Section III discusses the related studies based on.

Mobility awareness and provides the advantages and disadvantages presented in Table 3. Section IV and Section V discuss the research challenges of mobility awareness with MEC and 6G networks issues and future directions, respectively. Section VI concludes the paper.

2. Research background

The rapid advancement of mobile applications has led to the emergence of mobile edge as a viable option to fulfill the utility of time-sensitive applications such as AR and vehicle networks. Implementing MEC and 6G networks enables future technology that allows users to have good-quality services with high bandwidth and ultra-low latency to satisfy the network. This section provides a concept and research background of mobility awareness with MEC in the 6G network. The following is explained in detail in each subsection.

2.1. Mobile edge computing in 6G mobile networks

The 5G network and its successors will use a higher frequency beyond 5G and 6G. 6G offers a new improvement from various applications, encompassing improved mobile broadband, extensive machine-type communications, highly reliable low latency, sensing capability, and artificial intelligence (AI). 6G network will integrate edge and core computing as components of a single communication and computation infrastructure. Many benefits include improved AI access and compatibility with high-end mobile applications. As sophisticated solutions, mobile edge computing requires enhanced B5G and 6G [18]. MEC is an emerging technology created by the European Telecommunications Standards Institute (ETSI) and Industry Specification Group (ISG). This is a significant advancement for the 5G network and has been acknowledged by European public-private partnerships focused on 5G infrastructure, such as Nokia Networks, Intel, Vodafone, IBM, Huawei, and NTTDOCOMO [5,19].

In terms of ETSI, the following features characterize MEC as defined in Ref. [20]. MEC enhances network efficiency, security, and latency, enabling real-time applications such as AR and autonomous vehicles (Avs). However, MEC applications play a significant role in allowing highly reliable and low-latency communications in the context of 5G. This challenge is given by the figure, which describes MEC systems as hosts with user equipment located at base stations. Fig. 1 shows the implementation of the allying network cores and the base stations connecting the MEC servers. The clouds are also integrated with network cores, as shown in the figure below. The mobile edge and UE applications comprise edge systems (e.g., laptops, face recognition, etc.) [21]. The development of MEC brings a new future for wireless networks. Many concepts have emerged regarding the approach of mobile devices to users using MEC to minimize the latency relative to data processing. This will improve the transmission to the user.

Additionally, it produces a safety model for data storage due to the

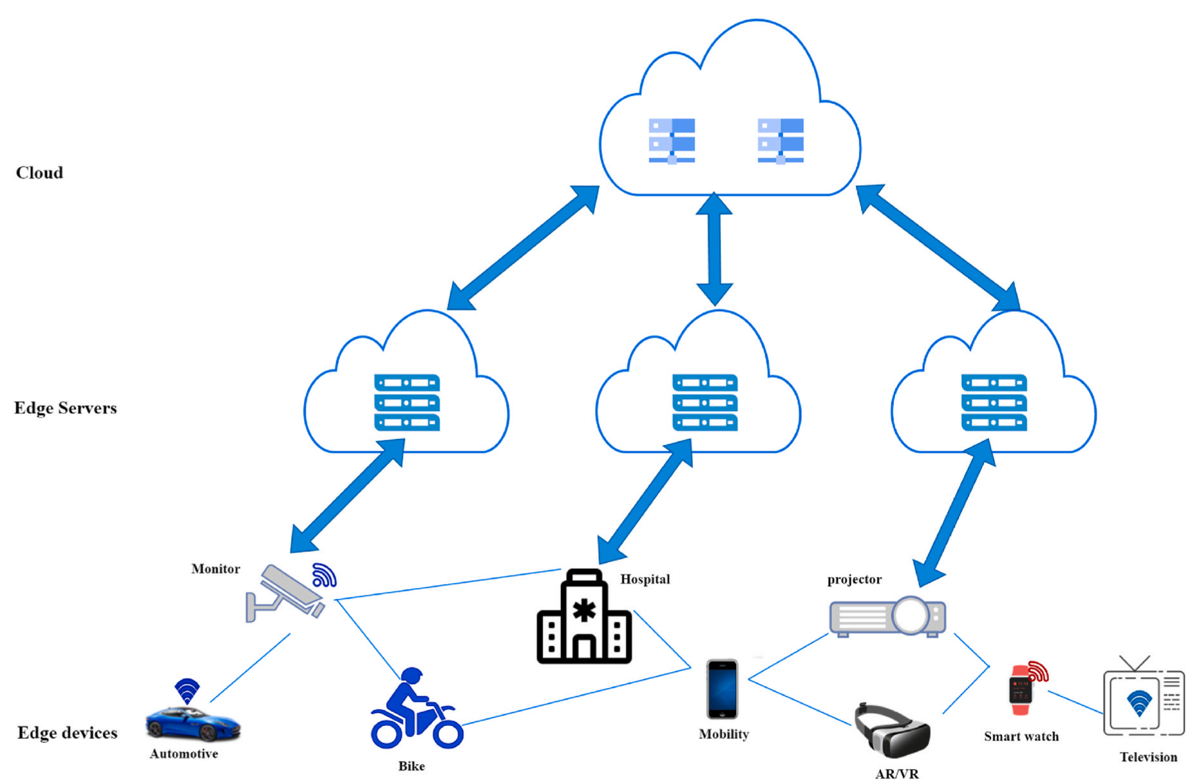

Fig. 1. The concept of the mobile edge computing.

edge network. MEC takes advantage of network congestion by transferring data from the network to the edge. This will allow edge intelligence to be realized in 6G networks [18,22]. 6G communications offer fast, seamless wireless connectivity, improving scalability, reliability, efficiency, power consumption, spectrum use, and reducing deployment costs.

2.2. Mobility awareness in mobile edge computing

The production of sensitive devices is getting increasingly advanced, and there is a growing need for mobile applications such as mobile cloud games [23], augmented/virtual reality [24], image/video processing APPs [25], and networking Vehicles to Everything (V2X) [26]. These applications require high computational power and have strict requirements for minimizing delays. The proposed application of V2X is used to identify the wireless hosts connected to different networks using Minnet-Wi-Fi. In this section, there is a creation scenario where the user's mobile moves from one station and changes the access point, which is connected to and can connect to the nearest by adapting to the Minnet-Wi-Fi. This scenario aims to analyze

The potential advantages of technical applications to deal with the seamless service movement between mobile edge nodes of different network operators with guaranteed service continuity. Taking into consideration options previously used to imitate the MEC environment for V2X communication, they were recognized based on a familiar environment [27,28].

Many applications can generate a lot of traffic and process workload, which leads to a battery depletion issue for mobile devices. In response, MEC has emerged as a promising computing paradigm to tackle the lack of capacity of mobile device resources. The MEC architecture, which includes the Mobile Edge Network (MEN), is specifically designed to accommodate

Numerous small cell base stations (sBSs) that are equipped with computational and storage capabilities [29]. The MEN play a crucial role in the MEC architecture, serving as the infrastructure that enables.

The deployment of MEC services and the management of MEN, thereby enhancing the overall performance of mobile devices.

The proposed design places a high priority on end-to-end (E2E) mobility, a crucial aspect to ensure uninterrupted service as the mobile users initiate the HO execution between multiple MENs. A solution known as MEC which has been put forward to address these challenges. MEC involves the deployment of a cloud computing platform at the edge of a Radio Access Network (RAN) near mobile devices and users [20]. An 'edge' in this context refers to a small-scale data center or a group of servers capable of supporting cloud applications. It is connected to a BS or access point, enabling neighboring devices to access it. The MEC paradigm significantly reduces end-to-end latency by leveraging a nearby edge node to handle the user workload, eliminating the need to rely on a distant cloud and thereby improving the performance of mobile devices. Fig. 2 represents the MEC system in the network scenario. Mobile users are transferring their computationally demanding and time-sensitive operations to the mobile edge networks comprising many base stations.

A central controller supervises and manages all sBSs. Users navigate inside the environment, and their paths can be anticipated using current methods. We aim to reduce the time it takes to complete tasks in the MEN by efficiently organizing and prioritizing different user tasks. The job scheduling information is initially uploaded to the BSs and subsequently gathered by the central controller. However, the challenge of placing dynamic service profiles, a complex and intriguing problem, requires revision. User-perceived latency results from both communication and computation delays [30].

Thus, the service profile of each user has been located at the closest MEC node, which could result in MEC nodes becoming overloaded and

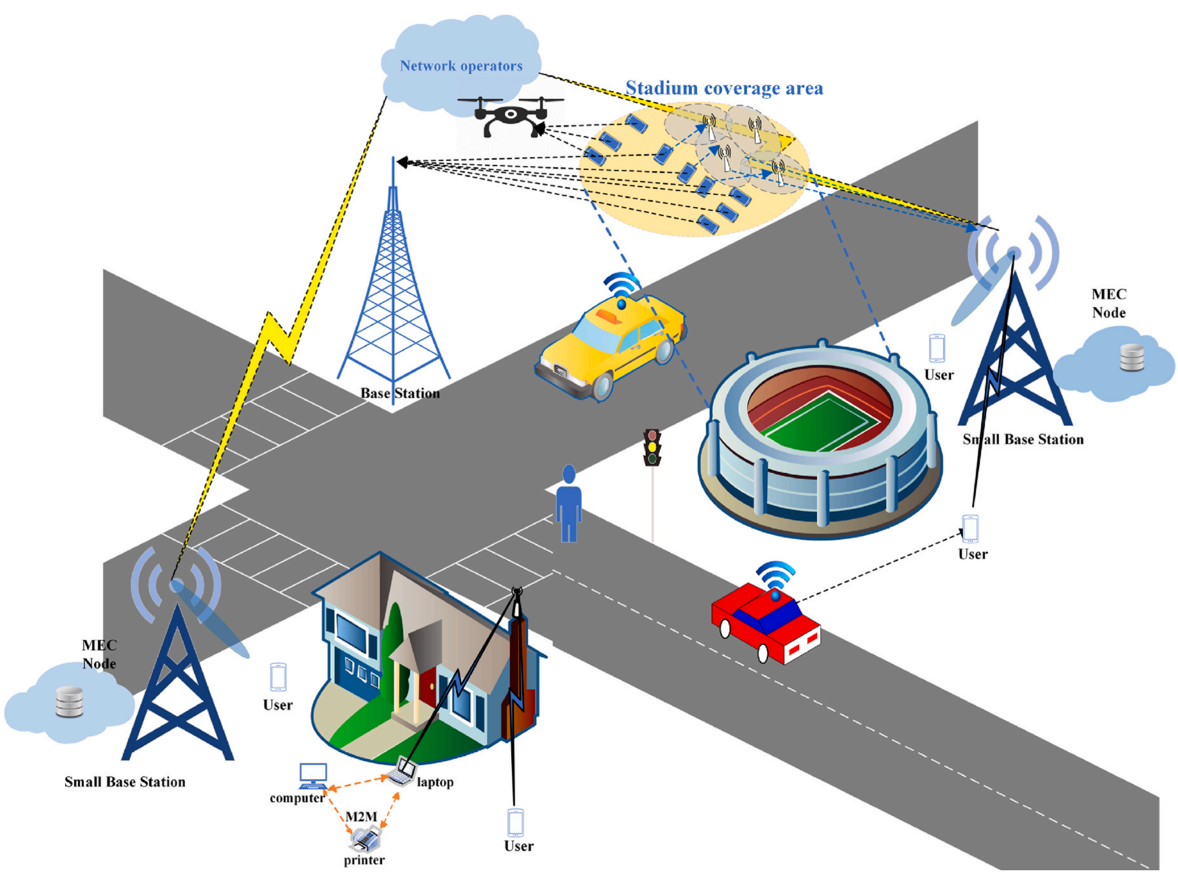

Fig. 2. Scenario for user mobility adapting with MEC applications for satisfaction transmission network.

causing a rise in computation latency. Alternatively, migrating services between several MEC nodes is necessary to meet the user's mobility requirements. Consequently, the continuous transfer of services results in extra operating expenses to clarify the utilization of costly wide-area network (WAN) bandwidth and power energy consumption [31]. The user experiences high intensity to satisfy mobility scenarios because of the MEC node, which facilitates data storage during the computational process. Therefore, the proposed scheme's integration of mobility awareness with MEC has resulted in significantly more efficient and effective service migration decisions than previous works. By leveraging user mobility predictions and optimizing migration policies using Markov Decision Process, the proposed solution demonstrated superior performance in reducing costs, minimizing delays, enhancing overall service quality, and offering practical benefits for real-world applications [32]. The relevant studies have been examined in comparison in Table 3.

2.3. Mobility awareness with AR applications

AR is a transformative technology that can change how individuals handle vast amounts of data. When AR technology is combined with mobility aids, it significantly benefits individuals with visual impairments. The integration of AR with 5G not only enhances its capabilities but also provides practical benefits, such as enabling simultaneous data access from multiple sensors, overcoming the limitations of low-quality cameras, stabilizing images, and providing practical and actionable information about the user's surroundings through a headset [33,34]. This integration can be achieved by simplifying and enhancing the accessibility of various applications. The evolution of this system is aimed at providing the latest advancements in 5G and AR networks for diverse applications [35]. However, the implementation of AR revealed many studies in AR technology for the development of the MEC network. In part, MEC will provide related work in AR optimization. For that reason, Huang Z et al. [36] proposed a technique for computing and storing capacity at the end device and network through edge cloud (EC) support.

The Mobile Augmented Reality (MAR) service decomposition employs a deep neural network with Long Short-Term Memory (LSTM) to facilitate prompt and effective proactive decision-making in real-time. To be more precise, the LSTM deep neural network is trained using optimal solutions.

Fig. 3 illustrates the service migration for users' mobility with seamless connection. This service allows users to migrate from one.

Location to another. The network evolution presented significant obstacles for the MAR

System in storing real-world data for AR access and understanding how AR applications may be effectively utilized with user interaction in the environment. This scenario explores mobility management's efficacy in enhancing AR apps' precision on linked devices. The growing popularity of mobile devices and the introduction of new generations of gadgets equipped with more precise sensors and cameras have made augmented and virtual reality technologies feasible. Over the last ten years, Internet services and data oversupply have maximized the mobile user [37].

According to Ref. [38], some applications require many resources and are highly dependent on accurate location data of the user and the environment (e.g., buildings, monuments). Some mobile services have already been developed based on AR technologies. These can help with navigation, provide contextual access to a wealth of geolocation content related to cultural assets, provide details about local events, and help with urban planning [39]. However, these services still lack more advanced and accurate tracking methods that are efficient enough for widespread use of the applications. This study illustrates how the user moves the localization item across an urban metropolis based on the mobility and AR application scenario [40,41]. The tracked object was delivered via the centralized cloud center.

Through MEC applications, AR apps make it easier for users to navigate the application while maintaining high precision and low latency signal transmission without signal loss. Despite the challenges associated with AR-based mobility in various subterranean environments, the user must physically navigate to the desired place. One of the upcoming problems for the new application in mobility management is the development of various features. The next-generation network will bring new resolutions for users while moving to different stations because of ultra-low latency.

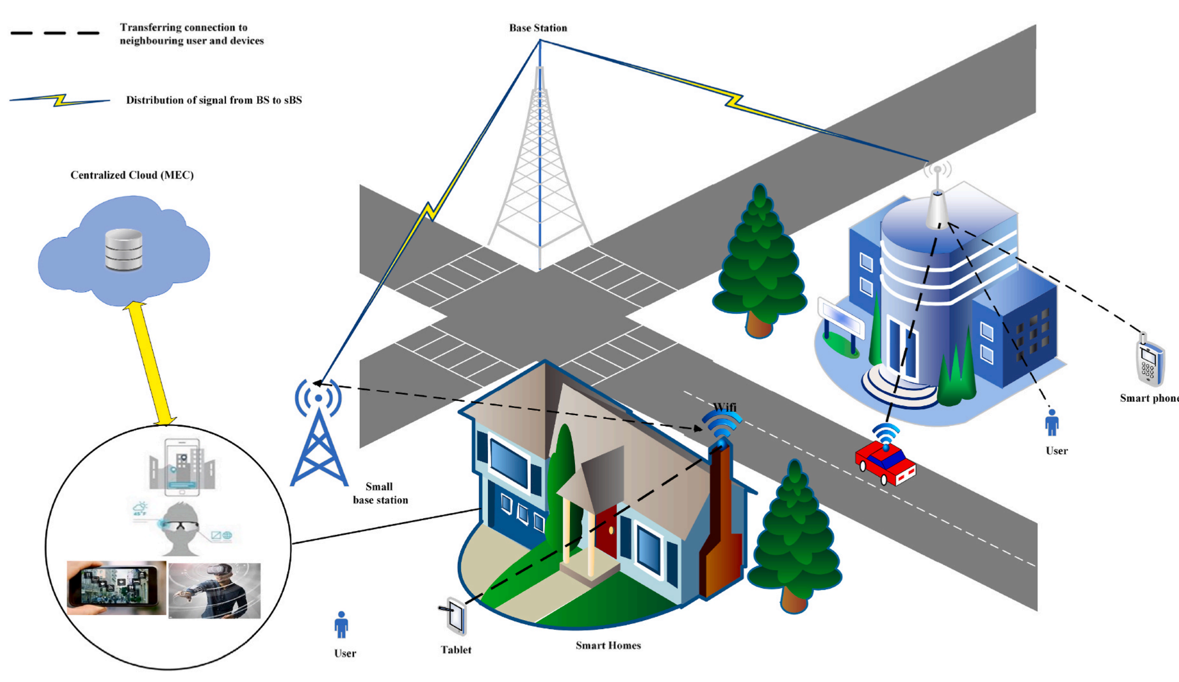

Fig. 3. Service migration enhance mobility awareness and facility seamless connectivity between users and other devices.

2.4. AR applications and their relationship with MEC and mobility awareness

Augmented Reality technology, a thrilling advancement, offers users the unique opportunity to perceive the real world through virtual devices. The extensive utilization of mobile devices, propelled by the ubiquity of mobile phones, empowers users to operate AR applications on their mobile devices, enhancing their mobility awareness [42]. The advent of next-generation networking technologies, such as 6G, brings forth many opportunities and challenges for AR applications. These technologies strive to achieve low latency and computational enhancements. Mobile Edge Computing is pivotal in this landscape, facilitating seamless communication between users and AR applications. However, the current35 MEC support for AR may not consistently fulfil expectations due to network disruptions induced by the instability of wireless connectivity and user movement, which are essential aspects of widely used AR applications [43].

For instance, researchers are currently studying the possibility of mobility management in MEC applications for future wireless networks to solve these difficulties. By scrutinizing user interfaces and connectivity, they strive to enhance AR experiences while maintaining low latency and efficient computational offloading, paving the way for a more seamless integration of AR and MEC. The MEC server possesses strong computational capability, enabling rapid processing of delegated tasks. The base station performs the task-forwarding function. We address that the user terminal works with AR applications. The function is user-terminal. The recognition application of augmented reality on MEC systems is elaborated on in Fig. 4. Initially, AR user terminals initiate the request for AR applications and transmit the necessary data to the MEC server at the base station. The user's MEC server also gathers data from nearby MEC servers and network status information to create offloading and resource allocation methods.

Furthermore, the MEC server is responsible for transmitting the offloading pathways and resource allocation strategies to the user terminals. The execution of AR activities on user terminals is carried out with the established offloading and resource allocation. The mobile AR program application and deployment processing function display performance information on the output. A key aspect of this functionality is the utilization of data information for external computing in the cloud, which encompasses several applications, such as interaction systems, rendering systems, and tracking. Utilizing systems and registration systems plays a significant role in advancing innovative AR applications [44]. Tracking enables the user to ascertain the present position of the computer simulation of the physical object. This technology commonly employs a combination of visual sensors, hybridization, and other types of sensors. The versatility of sensor-based tracking, frequently used in auditory, mechanical, and magnetic applications, is a testament to its wide range of applications and potential for innovation.

On the other hand, vision-based tracking involves using the camera to analyze the image from the present location in the actual environment [45–47]. The rendering systems receive the user's specified geographical location pathway as input, which is used to create the picture displayed to the user [48–50]. Indeed, a user can change their location before retrieving cached content on their mobile device. When establishing caching strategies for MEC systems, it is crucial to consider mobility-aware content placement and reducing power consumption by the BS and MEC host during content delivery. This approach is responsible for delivering information to the user. For AR applications, an external database called Centralize Cloud can be used to execute CPU processing remotely. The communication link that connects the user terminal and the central server for MEC must meet high demands due to the need for rapid transmission of high data rates [51]. On the other hand, 6G networks are anticipated to deliver wireless connectivity with high speeds and uninterrupted performance (see Table 1).

Consequently, the network will significantly enhance scalability, reliability, effectiveness, energy consumption, optimal spectrum utilization, and reduced deployment cost. Table 2 examines a comparative study of the existing works on AR and its relation to MEC and mobility awareness. The study table considers parameters such as computer paradigm (CP), KPI, applications, limitations, and study objectives. The table compares existing mobility and AR, where the indication 'No' means that mobility and AR are not considered. The indication 'Yes' means mobility and AR, considered in study papers.

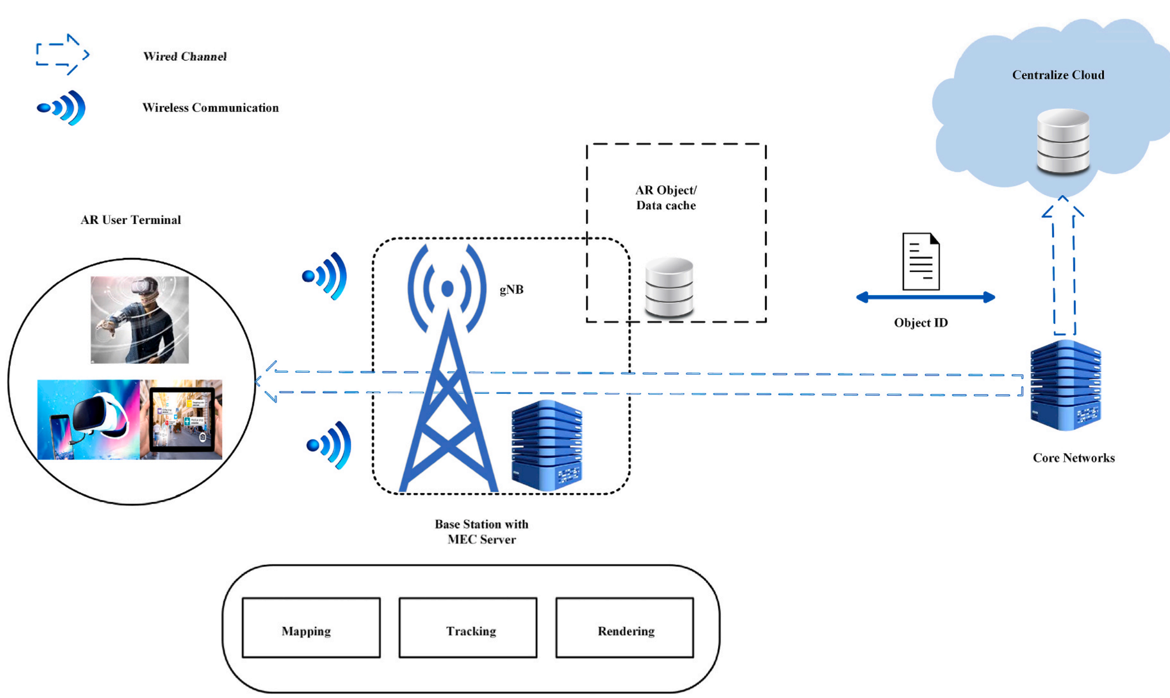

Fig. 4. Mobile edge computing on AR user terminal with mobility awareness to the BS.

Table 1
LIST of abbreviations

Abbreviations	Definition
3GPP	Third-generation partnership project
5G	Fifth generation
6G	Six generation
AI	Artificial intelligence
A2A	Application to application
AR	Augmented reality
AV	Augmented virtuality
B5G	Beyond Fifth Generation
BS	Base station
CPU	Central process unit
CHO	Conditional handover
CPSs	Cyber-Physical Systems
CP	Computer paradigm
D2D	Device to device
DL	Deep learning
DNS	Domain name systems
DRL	Deep reinforcement learning
eNB	Envolve nodeB
E2E	End to End
ETSI	European Telecommunication Standard Institute
FL	Federated learning
GA	Genetic Algorithm
GFT	Game Frame Time
gNB	Next generation nodeB
HetNet	Heterogenous network
HO	Handover
HMAOA	Heuristic Mobility-Aware Offloading Algorithm
IoT	Internet of Things
ISAC	Integrated Sensing and Communication
KPI	Keys performance indication
LoS	Line-of-sight
LTE	Long Term Evolution
MAR	Mobile augmented reality
MEC	Mobile Edge Computing
MDP	Markov decision process
ML	Machine learning
MobMig	Mobility-aware and Migration
NFV	Network function virtualization
NN	Neural network
QoE	Quality of experience
QoS	Quality of service
RAN	Radio Access Network
RSRP	Reference Signal Received Power
RSSI	Received signal strength Indicator
sBSs	Small cell base station
SDN	Software-defined networking
SINR	Signal-to-interference plus noise ratio
SPF	Service Failure Probability
UAV	Unmanned aerial Vehicle
UDN	Ultra-Dense Networks
UE	User Equipment
VANET	Vehicular ad hoc network
V2V	Vehicle-to-vehicle
V2X	Vehicle-to-everything
VR	Virtual Reality

3. Related studies

In this comprehensive survey, several papers thoroughly examine mobile edge, emphasizing mobility-aware computing, mobile edge applications with privacy, and applications such as IoT and task offloading. However, these surveys primarily focus on mobility awareness within the MEC network. While many publications discuss the mobile edge, they prioritize mobility-aware computing, mobile edge applications that prioritize privacy, and applications such as AR, IoT, and task offloading. However, these surveys approach mobility awareness by leveraging the MEC network in the following application. The research is meticulously organized in Table 3, providing a clear and sequential order for understanding.

In 2017, Sun Y et al. [61] discussed Energy-Aware Mobility Management (EMM) for MEC in UDN. This research is not only theoretical but also has practical implications. It addresses the challenges of integrating MEC with Ultra-Dense Networks (UDN). It proposes a user-centric EMM scheme to optimize delay and energy consumption for mobile users. The EMM algorithm leverages Lyapunov optimization and Multi-Armed Bandit (MAB) theories for efficient base station (BS) association decisions. The algorithm aims to minimize average delay while adhering to energy constraints, even when users have limited BS-side information and BSs dynamically switch on and off. Theoretical analysis and simulations demonstrate that the EMM algorithm achieves almost optimal performance without information about future system conditions. It also guarantees limited deviation in delay performance and energy consumption. The study offers valuable insights into how design parameters affect system performance and provides practical advice for implementing MEC in UDN.

In 2018, Ouyang T. et al. [30] discussed the challenges and solutions for dynamic service placement in MEC environments, considering user mobility and cost-efficiency. It emphasizes the delicate balance between service performance and the expenses associated with periodic service relocation. It reassures the audience that the proposed framework is not just a solution but a cost-effective solution. The framework aims to minimize user-perceived latency over the long term while adhering to a pre-defined migration cost budget. By utilizing Lyapunov optimization, the framework can make real-time decisions on service placement without requiring future information on user mobility. The work introduces centralized and distributed approximation approaches for efficiently finding near-optimal solutions to the NP-hard optimization problem. The proposed mobility-aware online service placement paradigm is effective and cost-efficient through theoretical analysis and trace-driven tests.

In 2018, Wang et al. [29] focused on reducing task execution delay in Mobile Edge Computing (MEC) by proposing a lightweight algorithm for task assignment that considers user mobility and network constraints. An accurate delay estimation scheme is also introduced to support precise offloading decisions on mobile devices. Simulation experiments demonstrate that the proposed approach significantly reduces task execution delay in MEC environments, leading to improved resource utilization and overall performance compared to existing works that do not account for user mobility. The study emphasizes minimizing delay within MECs. It presents a novel in-network task scheduling approach that jointly considers task information, resource availability, and user mobility, distinguishing it from previous works focusing on energy consumption optimization or single-task offloading.

In 2019, Peng et al. [28] introduced a novel Mobility-aware and Migration (MobMig) approach to address the edge-user allocation problem in mobile edge computing environments. Unlike traditional static optimization methods, MobMig is designed as an online decision-making process that considers edge users' high mobility. By leveraging mobility-aware and migration-enabled techniques, MobMig dynamically allocates users in real-time to achieve higher user coverage rates and reduce the need for reallocations. Experimental results demonstrate that MobMig outperforms existing approaches regarding user coverage and stability, showcasing its effectiveness in optimizing user allocation in dynamic mobile edge computing scenarios.

In 2019, Wu et al. [62] introduced a new technique for service selection in MEC. This approach integrates user mobility patterns and uses historical data to predict future user locations. The framework's primary goal is to optimize service provisioning efficiency. This mobility-aware service selection is an innovative concept that has the potential to significantly enhance resource allocation and user experience in MEC systems. However, the paper's lack of a comprehensive evaluation of the proposed framework's performance and scalability is a point of concern. To fully validate the effectiveness and practicality of this approach in diverse mobile edge computing scenarios, further empirical studies and real-world implementations are necessary.

In 2019, Yang et al. [63] proposed innovative task offloading schemes for vehicular edge computing networks to enhance connectivity and service quality. The authors address challenges faced by vehicular

Table 2
Comparison of studies on AR and its related to MEC and Mobility Awareness.

Ref. & Year	CP	KPI	Applications	Limitations	Objectives	Mobility	AR
Abdullah et al. [52] (2018)	EC	Percentage of failed, average network delay, average processing time	Driverless cars	AR for driverless cars is limited to other applications and needs a broader range of parameters to interact with MEC performance.	-Enhance the application performance. -Reducing latency and improving responsiveness when users are with the network.	Yes	Yes
Ren et al. [53] (2019)	MEC	Energy consumption and efficiency and delay optimization	Mobile AR and computation architecture	Lack of comprehensive real-world implementation for mobile AR	Implement a new computation architecture that integrates edge computing and enhances the QoE for MAR	No	Yes
Liu et al. [54] (2019)	MEC	Service failure probability (SFP): 90 %, BLER: 10^{-7}, latency constant ratio: 0.6.	AR services	-Simplified task model in AR services. -Lack of real-world validation limits the finding when enabling AR. -No mobility	Optimizing the code offloading to minimize the latency and reliability requirement can reduce the SFP of MEC-enabled AR services.	No	Yes
Zhan W et al. [55] (2020)	MEC	Task latency and energy consumption	New computing paradigm	Heuristic mobility-aware offloading faces problems in adaptability to network	Optimal system-wide user utility while balancing task latency and energy consumption.	Yes	No
Peng et al. [56] (2022)	EC	-Motion to photon latency. -Energy consumption. -Load balancing.	AR applications in healthcare Cyber-Physical Systems (CPSs)	MEC networks do not adequately represent the nature of user mobility, and AR implementation may face problems related to compatibility.	Secure AR applications in healthcare CPSs and user mobility in an edge computing environment.	Yes	Yes
Singh et al. [57] (2022)	MEC	-Game frame Time (GFT). -Partition Cost	AR and VR gaming	Potential issues in scalability and addressing diverse mobility in AR/VR gaming.	Reduce GFT and enhance the QoE for multiplayer AR/VR games by optimizing migration strategies.	Yes	Yes
Ateya et al. [58] (2023)	MEC	-Energy Efficiency. -QoS constraints -Latency Awareness	-Multi-user AR Games -Web-based AR applications -360^0 AR video streaming.	Constraints related to battery limitations, computing resources, and QoS requirements.	Develop an energy-efficient and latency-aware offloading for AR and SDN-based intelligent networks.	Yes	Yes
Toma et al. [59] (2023)	EC	-Average execution time: 0.17 ms for cloud, 3 ms for Edge, 5.9 ms for IoT. Partition tasks	Cloud service Website for Amazon or Google.	Due to the lack of compatibility between systems models, the evaluation model is based on synthesized workloads and a custom simulation environment.	Optimize the utilization of edge computing resources globally by developing an efficient algorithm and modeling edge computer systems for AR and soft real-time applications.	Yes	Yes
Ganesan et al. [60] (2024)	EC	-Latency -Packet loss rate.	AR/VR applications	Lack of study on the specific ML algorithms and slicing in AR and VR applications in 5G.	Integrate data prediction and slicing models to enhance EC for AR/VR applications in 5G.	Yes	Yes

networks by considering factors such as vehicle mobility, task completion latency, and system costs in their optimization models. They introduce location-based and mobility-aware offloading schemes for independent and cooperative MEC server scenarios, aiming to minimize task completion costs while balancing latency requirements. The study critiques existing works that need to consider vehicles' fast-moving nature adequately and emphasizes the importance of mobility and location awareness in task-offloading decisions.

In 2019, Wu C et al. [64] addressed the challenge of offloading mobile tasks in edge computing environments by considering the mobility of edge users. The proposed approach leverages a deep-learning-based method, SGAN, to forecast user trajectories and make real-time offloading decisions to edge servers or cloud resources. The study demonstrates a significant reduction in offloading failures and lower response times compared to baseline methods, showcasing the effectiveness of the mobility-aware approach. However, while the paper introduces innovative solutions for mobile task offloading, further research could focus on incorporating service-level agreement constraints and exploring additional QoS metrics to enhance the system model and address potential limitations.

In 2020, Zhan W et al. [55] investigated mobility-aware multi-user offloading optimization for MEC, focusing on offloading decisions and resource allocation among multiple users to enhance system-wide user utility. It proposes a heuristic mobility-aware offloading algorithm (HMAOA) to address the NP-hard optimization problem in task offloading, achieving superior performance compared to baseline algorithms. The study highlights the importance of considering user mobility, resource constraints, and task latency requirements in MEC systems. However, the related studies highlight resource allocation challenges in multi-user scenarios and the need for efficient algorithms to optimize system utility while considering user mobility and offloading decisions.

In 2020 Saleem et al. [65] addressed the challenge of optimizing task scheduling and resource allocation in MEC networks considering user mobility. The study introduces a mixed-integer non-linear programming problem formulation to decrease task offloading latency while accounting for user energy constraints and distributed computation capacities. Two approaches, a genetic algorithm-based scheme and a Mobility-Aware Task Scheduling heuristic, are proposed to solve the optimization problem efficiently. The critique of this study highlights the importance of incorporating user location information in task scheduling for mobile users in distributed MEC scenarios, emphasizing the need to address the power-delay tradeoff and task diversity in cooperative MEC systems.

In 2020, Wei et al. [66] presented a novel approach to service caching in MEC environments by utilizing user mobility patterns to predict service requests and optimize caching strategies. The proposed algorithm leverages historical data and user trajectories to enhance the efficiency of service allocation at the edge-cloud server. By incorporating mobility awareness into the caching strategy, the system aims to reduce latency and improve overall performance in IoT applications. However, the study acknowledges the challenges of acquiring absolute service datasets due to privacy concerns and highlights the need for further research. The paper contributes valuable insights into the intersection of mobility prediction and service caching, offering a promising direction for future advancements in mobile edge computing.

In 2021, Maleki et al. [67] addressed the challenge of making intelligent computation offloading decisions to decrease the time applications take to complete. The study presents the utilization of Matrix Completion, an effective machine learning technique, for forecasting future application specifications and user mobility. Additionally, it explores employing sampling-based and greedy-based offloading

Table 3
Comparison table for all related studies based on mobility awareness and mobile edge computing.

Ref	Year	Problem addressed	Contributions	Network types	KPI	Simulators	Applications specifics	Advantages	Disadvantages
[61]	2017	The integration of MEC with dense deployment of BS is a new challenge in mobility management, which aims to optimize delay performance and user energy consumption.	Proposed EMM scheme offers a comprehensive and innovative solution to mobility issues in MEC-enabled UDN environments, enhancing system performance and user experience.	Mobility aware and MEC	Energy and delay	MATLAB	Mobile networking	High mobility while the user move	Performance loss due to low energy
[30]	2018	Challenge lies in effectively migrating services across multiple edges to maintain user mobility patterns without excessive costs.	Introduced a novel online service placement framework that utilizes Lyapunov optimization to tackle the issue of dynamic service placement in ME environments.	Mobility aware and MEC	Energy	Python	Mobility aware	Lower end-to-end latency	Computation capacity of edges
[29]	2018	This study uses a lightweight algorithm to optimize task assignment in MEC for multi-task scenarios, aiming to reduce execution delay.	The paper presents a lightweight algorithm for task assignment in MEC, demonstrating its effectiveness through simulation experiments.	User mobility and MEC	Task execution delay	MATLAB, NS-3	Mobile environment	- Reduction of task execution delay in MEC. - Improved resource utilization at the MEC	User mobility patterns or task characteristics not extensively explored in the study
[28]	2019	The paper addresses the edge-user-allocation problem in MEC environments by proposing a mobility-aware and migration-enabled approach, MobMig.	proposed MobMig approach, which is a mobility-aware and migration-enabled method for online edge user allocation in MEC	online edge user and MEC	–	IBM CPLEX	–		Ignore the mobility of edge users and edge user allocation.
[62]	2019	Traditional service selection methods in MEC systems are inefficient, neglecting user mobility patterns, leading to suboptimal resource	Proposed solution introduces a mobility-aware service selection framework for MEC systems and mobility data to predict future user locations and dynamically adjust service selection.	Mobility aware and MEC	Service latency and availability	Python	Mobility service	- Optimize service selection in MEC - Enhance the overall user experience	- Lack of detailed analysis on scalability and performance. - No potential challenges or drawbacks associated with incorporating user mobility
[63]	2019	This paper addresses efficient task offloading in vehicular edge computing networks to minimize system costs while meeting latency constraints.	Introduced mobility-aware and location-based task offloading schemes for independent and cooperative MEC servers in Vehicular Edge Computing Networks.	Mobility aware and MEC	System costs and ask completion latency	–	Vehicular edge computing networks	- Efficient resource utilization. - Enhanced connectivity and service quality. - Scalability and adaptability	- Complexity of optimization. - Dependency on accurate mobility prediction. Communication overhead
[64]	2019	The problem is the inefficiency of existing task-offloading strategies in MEC environments due to the neglect of user mobility.	introduced mobility-aware approach to task offloading in MEC environments to predict user trajectories and develop an online offloading algorithm based on QoS.	Mobility aware and MEC	Offloading failure count, response time, and QoS	–	Mobile applications	- Improved user experience. - Enhanced offloading success rates.	Complexity and computational overhead
[55]	2020	This research aims to enhance the efficiency of offloading decisions and resource allocation in MEC systems.	Proposed HMAOA for optimizing offloading decisions and resource allocation MEC systems considering user mobility and system-wide utility.	Mobility aware and MEC.		MATLAB	Mobility aware offloading	- High performance in optimizing system-wide users. - Resource allocation in MEC.	- Computational resources needed.

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Table 3 (*continued*)

Ref	Year	Problem addressed	Contributions	Network types	KPI	Simulators	Applications specifics	Advantages	Disadvantages
[65]	2020	proposes a mixed-integer non-linear programming problem to optimize task execution in a D2D-enabled cooperative MEC network,	Aimed to efficiently solve the optimization problem by considering user mobility, distributed resources, and energy constraints in MEC.	Mobility aware and MEC	Latency and energy	MATLAB	Communication and computation resource	- Efficient Optimization. - Consideration of User Mobility	- Computational complexity, especially in large-scale networks.
[66]	2020	mobility-aware service for IoT, optimizing caching strategies to enhance systems.	Proposed mobility-aware service for IoT, using mobility to predict service requests and reduce latency.	Mobility aware service caching and MEC	Service cache hit rate and service response time	–	IoT	- Optimize service caching strategies. - Improved system efficiency. - Reduced latency in IoT applications.	
Ref	Year	Problem addressed	Contributions	Network types	KPI	Simulators	Applications specifics	Advantages	Disadvantages
[67]	2021	aims to improve user experience and performance by optimizing offloading decisions in edge computing, considering user mobility and application	Innovated offloading methods for mobility-aware computation offloading in edge computing, utilizing Matrix Completion for optimal decision-making and reduced migration rates.	Mobility aware and MEC	Migration delay execution time and migration rates	MATLAB	Computation offloading	- Reduced migration rates. - Improving application performance and user experience	Future application specifications and user mobility uncertainty.
[68]	2021	enhancing the effectiveness of offloading execution, task processing, and maximizing energy efficiency in MEC.	Proposed model optimizes task scheduling, server utilization, and resource allocation for efficient offloading in MEC environments, considering mobility.	Mobility aware and MEC	Energy efficiency, offloading time, and task drop rate.	-	Mobile applications	Task prioritization and energy efficiency considerations.	Evaluate the scalability and effectiveness of the proposed mobility-aware offloading management.
[69]	2022	Presentation of innovative algorithms for optimizing task offloading in MEC, addressing resource constraints and battery capacity issues to reduce energy and latency.	proposed the use of Mobile Device Selection Algorithms and Joint Social-Aware and Mobility-Aware Computation Offloading Algorithms to optimize task offloading in MEC environments.	Mobility aware and MEC	Delay	iFog sim	Traffic management analytics	Improved offloading success rates, Reduced energy consumption, and Optimized task completion times.	Lack of extensive real-world validation and scalability analysis
[70]	2023	Conducting a mobility-aware edge server placement method to optimize response time by addressing unbalanced workload caused by mobile users.	proposed a two-stage solution for mobile edge server placement, utilizing BOMN for offline and BOCG for online, balancing query volume and response time.	Mobility aware and MEC	Query throughput and Response time	Python	Server localization.	Enhances the fairness of response times. Improved query throughput and response time in MEC	Lacks a detailed discussion on the potential limitations or challenges of implementing the proposed mobility-aware edge server.
[71]	2024	Optimizing task offloading in MEC networks by integrating task migration and cache-assisted techniques, considering mobile users.	Proposed a CMHA to optimize task offloading efficiency by intelligently migrating tasks based on mobile users' mobility patterns and minimizing system costs.	Mobility aware and MEC	Delay and energy consumption	MATLAB	-	- Reduce system delay and energy consumption. - Enhancing task offloading efficiency.	Limitations in scalability and generalizability to diverse network

approaches to make decisions that minimize turnaround times. While the paper provides valuable insights and proposes innovative solutions, it could benefit from further evaluation and comparison with existing state-of-the-art studies regarding scalability, accuracy, and real-world applicability to strengthen its contributions to edge Computing.

In 2021, Guan et al. [68] presented a mobility-aware offloading management scheme in sustainable MEC, addressing challenges in intra-cloudlet and inter-cloudlet offloading processes. By proposing a priority-based queue model and utilizing a Particle Swarm heuristic, the model optimizes task priority and server utilization scheduling within Cloudlets. The technique for selecting resources in an energy-aware inter-cloudlet improves the execution of offloading tasks and increases energy efficiency. The study contributes to the field by integrating mobility patterns, task heterogeneity, and system dynamics into a comprehensive offloading framework. However, further research could focus on refining workload prediction methods and validating mobility models to enhance the model's applicability and efficiency.

In 2022, Xu et al. [69] Mobile Device Selection Algorithms and Joint Social-Aware and Mobility-Aware Computation Offloading Algorithms are novel algorithms that could revolutionize task offloading in mobile edge computing environments. These algorithms, which consider social relationships, location correlation, and mobile activity, have the potential to significantly reduce energy consumption and latency while enhancing offloading success rates. The study addresses the limitations of existing works and introduces a novel approach by incorporating social-aware and mobility-aware elements into computation offloading strategies. While the initial results of these algorithms are promising, further research is needed to explore scalability issues and real-world implementation challenges, thereby validating their effectiveness in diverse mobile edge computing scenarios.

In 2023, Chen et al. [70] presented a novel approach for mobility-aware edge server placement in MEC, considering dynamic user movements and quality of service metrics. By formulating the problem as a temporal multi-objective optimization challenge, the authors propose a two-stage solution involving an offline deployment phase using the BOMN algorithm and an online tuning phase based on the cooperative game theory (BOCG) algorithm. The study demonstrates the efficacy of the proposed method through extensive experiments on real-world datasets, showcasing improved performance compared to

Baseline algorithms. While the paper significantly contributes to optimizing edge server placement, further research could explore predictive models for anticipating user movements and enhancing the overall deployment strategy.

In 2024, Lai et al. [71] addressed the issue of task offloading in MEC networks by considering mobile users' mobility and repetitive task computation. The study introduces a task migration strategy to handle task offloading failures due to user mobility and utilizes cache-assisted techniques to decrease redundant computations. The paper aims to minimize offloading costs for mobile users by optimizing task migration and caching strategies. The proposed cache-assisted mobility-aware heuristic algorithm outperforms benchmark algorithms regarding computational efficiency and cost reduction. However, the study acknowledges the need for further research on caching schemes to enhance cache hit rates, minimize offloading latency and energy consumption, and the potential for applying deep reinforcement learning in task offloading policies to optimize MEC networks further.

Several studies have explored mobility awareness with mobile edge computing, providing valuable insights into mobility management task offloading, service selection and migration, service cache, and user offloading. For instance, one theoretical construct is called the predictive models for user mobility concept, which has practical implications in the field by enabling service providers to anticipate user movements and optimize service delivery. Another example is the efficient task offloading strategies, which can be applied in real-world scenarios to decrease network congestion and improve user experience. These parameters are not just topics of interest but also crucial factors that shape the studies of mobility awareness and MEC, making our research directly applicable to the challenges faced in the industry.

Our research holds the potential to revolutionize mobility management issues with MEC. We have employed various innovative techniques, including heuristics, mobility-aware computation offloading, and cache-assisted mobility heuristic algorithms, which have proven to be highly effective in enhancing computational efficiency and optimizing task offloading in mobile edge computing. However, these techniques have their limitations. For example, the heuristics approach may only sometimes provide the most optimal solution, and the cache-assisted mobility heuristic algorithms may require significant memory resources. Nevertheless, the introduction of ML types, such as unsupervised learning and deep reinforcement learning, has opened up new avenues of research. Unsupervised learning, or Matrix completion, predicts future applications and user mobility, enabling smart offloading to reduce time consumption in an edge computing environment. On the other hand, deep reinforcement learning assigns the computer offloading tasks in MEC. It significantly enhances the efficacy and effectiveness of the task-offloading process, inspiring further exploration in this field.

Further investigation is not just necessary but crucial to developing a more effective MEC that enhances performance by moving sensitive latency from mobile devices and the cloud to a server located at the edge. The utility connection between mobility awareness and MEC minimizes the processing time delay while enhancing the quality of experience, underlining the importance and urgency of our research in this area.

4. Research challenges

With the advent of next-generation networks (5G and 6G) and MEC applications, the academic community has been at the forefront of identifying and addressing a variety of mobility management-related challenges. This section provides an overview of the mobility awareness and management cases used to solve many MEC issues by integrating 6G. These issues, such as accurate monitoring of user mobility positions, reliability and mobility, service migration, task offloading, latency, seamless HO, edge caching, and computation, are being tackled by academics, underscoring their invaluable role in this field.

4.1. Reliability and mobility

The evolution of 6G networks encompasses several challenging circumstances, namely vehicular and mobile networks with constant mobility [18]. Pereira, J. et al. [72] evaluate the reliability of fog computing for intelligent mobility applications in Vehicular Ad-Hoc Networks (VANET). Fog computing is a paradigm that needs to improve user mobility, such as mobility awareness and speed response time. Most challenges to implementing fog computing in VANETs include limited communication, efficient data management, security, and service protection. This research proposes a hybrid VANET architecture to address these issues and evaluate vehicular mobility performance. However, deploying MEC alongside user mobility challenges reliable and uninterrupted virtualized network services in urban areas. Our studies employ optimization problems, a crucial tool, to facilitate the mobility of mobile users with sensitive virtualized network services. This research has direct implications for real-world scenarios, as it seeks to minimize the cost of user requests while maximizing the cumulative utility of admitted requests [73,74]. The network architectures fluctuate in these cases due to communication paths between users and base stations. However, MEC applications require minimum latency and high reliability to improve users' QoS.

4.2. Service migration

An essential challenge in MEC is the seamless service migration [75–77]. Service migration transfers a user's service from one MEC node to another when user mobility or network circumstances change [78–80].

Within a distributed architecture, one particular task has the potential to be processed by multiple computing nodes. This can be accomplished by integrating the functions or following a pipeline. Parallel processing can enhance the overall computational speed but at the expense of increased system complexity. To evaluate the issue of service migration, we need to determine the best methodology that will provide solutions.

However, Chen W et al. [81] proposed a solution to ensure QoS and prevent interruptions of mobile edge computing during service migration. The proposed solution combines deep recurrent Q-learning and Markov decision processes. The objective is to reduce MEC latency and energy consumption while maintaining fair user delay. Deep learning will enhance service quality and mitigate interruptions in MEC by relocating services to the edge. The system presented in Ref. [78], introduces a novel architecture for mobility-aware service migration in small-cell MEC. The aim is to simplify decision-making and employ reinforcement learning to enable real-time service migration decisions. In addition, Wang et al. conducted a study on the topic of MEC in Ref. [79]. They introduced an efficient approach for dynamic service migration called Service Migration Deep Q-learning (SMDQN).

Service migration is a process that often triggers trust concerns due to the involvement of multiple organizations managing MEC hosts. This situation escalates security concerns, especially when transmitting data from a trusted source MEC host to an untrusted destination MEC host. However, the potential of blockchain technology to address these trust concerns is promising. Despite the need for existing blockchain systems to improve their response time for distributed applications, blockchain technology has shown the potential to mitigate trust concerns. The current algorithms for mobility-aware service transfer primarily rely on the user's pre-determined mobility habits [82].To ensure uninterrupted services to end-users with unpredictable movement patterns, sophisticated algorithms become crucial.

Yuan Q et al. [83] researched joint service migration mobility challenges in vehicular edge computing using a multi-agent deep reinforcement learning algorithm. The algorithm aims to reduce system costs and ensure service delays within communication resources, processing power, and road capacity limitations. With the sixth generation developing wireless networks, vehicle networks will take advantage of driving in real-time. The implementation of 6G enables the internet of vehicles to ensure the quality of movement of user mobility and minimize energy consumption. The objective is to optimize energy consumption with a specific delay. The algorithm used, such as strength Pareto evolutions, improves the efficiency and reliability of IoV service during user mobility [84]. Exploring the evidence supporting the improved efficiency of service migration in edge computing, we find an efficient and robust system. Edge computing features such as reducing latency, efficient bandwidth, improved service efficiency, and dynamic service migration contribute to this confidence in its capabilities [85–87]. These studies unequivocally demonstrate that edge computing's proximity, reduced latency, and efficient resource utilization are not just features but powerful tools for optimizing service migration and enhancing overall system performance, providing a reassuring outlook for the future.

4.3. Edge caching and mobile computing

While previous research has explored the concept of edge caching in MEC, our study takes a novel approach. We delve into implementing mobile environments with crucial mobility awareness and MEC and develop a numerical analysis of communication caching and computing. This has led to a unified computation method for MEC. Our research is not just about optimizing bandwidth usage through various strategies but also about using edge caching and computing in the context of AR and the haptic Internet within the 5G network infrastructure to enhance the overall network processing capabilities. We believe that the integration of edge caching and computing in the context of AR will establish a user experience framework for MAR and IoT applications. However, we also recognize the challenges posed by increased network traffic and energy consumption due to the proliferation of AR and virtual applications. Our research is dedicated to addressing these issues that arise with the influx of more mobile users and their impact on the speed, bandwidth, and backhaul network of wireless links [88–90].

4.4. Latency and seamless handovers

Maintaining a reliable and effective network is a crucial concern in mobility management, owing to the significant capabilities of transmission networks [91,92]. Furthermore, mobile users opt to utilize their cell phones as a means of containment, circumventing the need to transfer data to edge servers. Several research topics have been addressed in container migration across edge servers, explicitly focusing on optimizing latency and hosting paths for efficient service delivery. The proliferation of mobile devices has led to a significant surge in data traffic on mobile networks. The primary challenge associated with the handover authentication procedure is the delay reduction. Studies in Refs. [93,94], and [95] show that using essential identification features in MEC can effectively reduce the delay that comes with HO authentication. The proposed system architecture uses an SDN approach to simplify handover authentication in mobile edge computing (MEC) cyber-physical deployments, a significant step towards overcoming these challenges. This design, a timely response to the limitations of traditional cloud computing, aims to address privacy concerns related to cyber-physical systems (CPS). The exploration of energy consumption among users in CPS and data security in edge computing is a central focus of software-defined networking (SDN)-based HO. However, significant time delays reduce the effectiveness of an HO authentication. The seamless handover system, employed in MEC/SDN-based vehicular networks, is a sophisticated approach implemented in 5G networks to facilitate interaction between vehicles and devices. This paper presents the development of HO mechanism that enables seamless communication between V2V and V2X communication [96]. In addition, the author's proposal for a complex multi-access edge computing environment that incorporates a smooth handover connection and an SDN [97–99] is a significant contribution to the field, promising to revolutionize how we manage mobility and edge computing.

4.5. Task offloading

Mobile devices have inherent limitations in processing speed, memory capacity, and storage capabilities. Mobile apps need a robust computational capacity and a fast Internet connection, which are not readily available on mobile devices. Hence, under such circumstances, it becomes feasible to transfer resource-intensive operations to external platforms like cloud, grid, and MEC servers, a process referred to as task offloading [100]. In the given context, the constrained processing capabilities of mobile devices impede computing resources and impact the battery life of these devices, hence rendering it unfeasible to fulfill customers' QoS requirements. The current offloading study assumes that UEs stay immobile while the workload is transferred to the MEC host. However, the frequent transfer of responsibilities owing to mobility significantly hampers the advantages of task offloading. Further, it is a cause for concern as task offloading methods must integrate mobility. Mobility's adverse effects on offloading algorithms' performance, primarily due to the expenses associated with job transfer and re-offloading, are a critical issue that needs to be addressed. Re-offloading might occur when the entire task is not transferred, and at the same time, the user switches to a different BS [69]. Most previous research on mobility problems assumes that complete system information, such as MEC/BS side information and predictable mobility patterns, is available [101].

The primary challenge is utilizing a learning algorithm to retrieve system knowledge without comprehensive data. Conventional machine learning methods have yet to successfully uncover the necessary information because the data contains several modes. This study is crucial in addressing the challenges related to mobility and resource constraints, underscoring its importance in mobile computing [102].

This study aims to divide the scheduling technique that examines the computational and storage capacity of the servers. The authors suggest using the deep reinforcement learning method to determine the best offloading strategy based on information about the local link and node state during the channel coherence time [103,104]. However, further exploration is needed to fully enhance intelligent offloading algorithms by considering mobility.

4.6. Accurate tracking for mobile user positioning

Mobile users frequently encounter connection problems with edge devices due to constant movement. The mobility issue is a prevalent concern that needs careful consideration within the context of MEC. When a user or mobile device changes location, it traverses distinct geographical areas on each occasion, resulting in a decline in performance [61,105]. Numerous suggestions have been made to address the issue of mobility. The mobility-aware dynamic service placement efficiency in the Long-Term Evolution (LTE) Network is suboptimal. The use of Lyapunov optimization and Markov optimization techniques makes it easier to improve the performance of mobile edges while minimizing latency while avoiding long-term costs. The technical operation of MEC involves a mobility-aware and delay-sensitive service. However, challenges arise when users seek access to ensure dependable and uninterrupted virtual network operations. The idea put forth by MEC aims to decrease the latency experienced by mobile consumers. The mobility issue is a recurring concern that needs careful consideration within the context of MEC. When a person or device undergoes a transition from one location to another, it traverses distinct geographical regions on each occasion, leading to a decline in performance, as indicated by Refs. [30,73,106]. The proliferation of mobile devices designed for mobility and personalized usage has presented several challenges that impede users' ability to transition between locations. The current approach does not adequately address matching user location assignment and time delay with user mobility. This paper introduces a potential strategy for reducing latency in a D2D network by optimizing job scheduling and assignment for mobile users. To address the formulated mixed-integer nonlinear programming problem, the GA collaborates with the Evolution Scheme. A suggestion for a task scheduling approach known as low-complexity, mobility-aware task scheduling has been proposed. Both GA and multi-agent task scheduling can reduce latency in edge networks that require significant computational resources. The current allocation and load-balancing techniques in MEC have been designed with a primary focus on addressing the issue of mobility, which is the predominant challenge related to computing resource management. This study identifies a research gap in the optimization problem of the interplay between latency, processing capacity, and mobility [28,65,107,108]. Therefore, the accurate monitoring of user mobility positions in 6G lies in leveraging high-resolution sensing with large bandwidths and arrays, utilizing reconfigurable intelligent surfaces, and integrating positioning and sensing as essential system components. These advancements aim to address the stringent requirements of 6G use cases and enhance the accuracy and reliability of mobile user tracking in next-generation networks, ultimately benefiting the end users [109,110].

5. Future research directions

This section provides a potential direction for future research to establish mobility awareness with mobile edge computing enabling 6G networks. The following future research has been summarized as follows.

5.1. Machine learning

Numerous proposals have been put out in network technology to attain the objectives set for 5G and 6G mobile networks. Nevertheless, implementing these novel solutions poses many challenges, transforming the networks into intricate management quandaries. In this scenario, Heterogenous Networks (HetNets) have impeded the effective operation of many utilities, such as mobility management, task offloading, latency, and smooth handover, while ensuring extensive coverage. The ML models were converted to data-driven models to enhance the efficiency of mobility and MEC networks in ML models, which are the most advantageous features of 5G and 6G mobile networks [42,111]. ML algorithms are essential for the progress of 5G technologies and the establishment of 6G networks [112]. Machine learning is a discipline within the realm of AI that provides auspicious tools for the analysis of data systems [113]. In the field of HO management, State-of-the-art algorithms based on ML methods have been shown to enhance the quality of experience (QoE) in LTE networks. These algorithms aim to provide a system enabling the handover algorithm network to effectively target the Evolved NodeB (eNB). Evaluating a state-of-the-art ML technique and an optimal HO mechanism allows us to determine the eNB that exhibits superior QoE while minimizing latency. This study examines the utilization of Key Performance Indicators (KPIs) such as reference signal received power (RSRP) and reference signal received quality (RSRQ) to gather data about the QoE [114]. Li and colleagues [24] proposed the implementation of the Elman network and conducted a comparison between two distinct network areas. The handover determination algorithm was utilized with the LTE-R systems to execute the handover procedure in situations where the signal strength was deemed inadequate. So, the neural network (NN) algorithm works with a machine learning approach, and the receiver signal strength indicator checks the handover prediction at set times to gather helpful information. In mobility management, algorithms utilizing machine learning techniques were employed to forecast the performance of computational servers and analyze field data collected from a densely populated urban region. The determination of the handover choice is contingent upon using the method presented inside the neural network. The data from 5G cell phones and the measured KPIs are more accurate than ever, reaching up to 70 % of the RSRP. Moreover, the utilization of the anticipated handover probability in MEC results in varied handover decisions, hence enhancing the accuracy of prediction in neural network systems [115,116].

5.2. Dynamic resource orchestration

Mobile edge computing topologies can bring many functionalities to dynamic resource orchestration systems [117]. However, dynamic resource allocation improves the performance of the wireless generation network's mobile edge computing, considering various needs such as computational intensity, ultra-low latency, and reliability. Dynamic resource orchestration proposes several solutions in virtual mobile edge computing environments [118,119]. Although the utilization service function chain (e.g., SDN) improves network performance and IoT applications during the optimization algorithms of SFC, this part will summarize the dynamic resource orchestration of the edge into three aspects: computing resources, storage resources, and network resources.

5.2.1. Computing resources

In MEC, computing resources are tied to the resources to process and perform computing activities closer to the network edge. However, Resources, including central processing, memory, storage, and network bandwidth, must handle mobile apps and services on edge nodes. The primary goal of computing resources is to enhance network efficiency and allocate transmission resources at edge nodes to ensure minimal time delay for end users [118–122].

5.2.2. Storage resources

Storage resource-based edge nodes are crucial components of edge computing that provide memory capabilities for storage and data sharing. The performance of these storage resources is evaluated in a heterogeneous network, where data storage is transmitted to the base stations, including macrocells, small cells, and Pico cells, all of which contribute to network performance. However, the memory capacity of the edge server is limited compared to the cloud server, leading to the movement of the end user to the edge node. This limitation poses a significant challenge for future large-scale edge computing. To overcome this challenge, we propose an innovative approach-applying a dynamic method in deep reinforcement learning to enhance collaboration on storage resource allocation. This novel solution promises to improve the performance of the memory resource model significantly [123,124].

5.2.3. Network resources

Network resource optimization is a critical issue in edge computing environments. Network resource allocation in the edge node reaches the limit to transmit the signal to the base station's terminal. However, the excessive growth of mobile users manifests an impact of network traffic on resource allocation. Usually, the network resources are used to maximize the performance of the next-generation network in edge node environments and increase the necessary resources of the host with the most processing tasks in the core network, such as loading balancing and bandwidth [118]. The objective of network resources in edge-orchestrated computing is to allow data transfer between mobile devices and edge servers. Efficient resources improve mobile application performance, reduce energy consumption, and increase the user experience. Therefore, mobility awareness in computation offloading and resource allocation in edge computing use deep reinforcement learning to improve user mobility performance [125,126].

5.3. Software-defined network

By addressing the dynamics of many new network technologies and increasing network capacity, SDN technology is a method for improving network administration [127,128]. The approach to handover decisions is the primary source of trouble while managing various network architectures. One example is the SDN/Network function virtualization (NFV)-based HO decision mechanism for ultra-dense 5G mobile networks proposed in the SDN concept. In addition to reorganizing IoT data at the mobile edge, SDN allows the MEC in cyber-physical systems (CPS) to guarantee defensive communications. Assuring frequent SHS turnover in small cells is the foundation of the SDN-based handover authentication mechanism. Another way it prevents attacks is by making sure all Internet security protocols and apps are secure automatically. Nevertheless, SDNs avoid needless and frequent handoffs. BS virtualization is the main emphasis of mobile network virtualization related to HO information. What we mean by "NFV" is the transfer of network functionality from dedicated appliance hardware to software-based applications. Data collection, processing, V-cell construction, and handover execution are the four main components of the suggested HO system. An assessment report from the mobile node, the serving base station, and the base station that is being considered for handover is included in the data processing. To determine the optimal location of base stations for mobile users based on their various behaviors, data processing is carried out to provide QoS for each BS surrounding region [97,129,130]. The primary goal is to deploy an MEC controller that incorporates SDN control and suggests a sophisticated handover algorithm for use in network design. However, the research compares and contrasts two objective problems. The primary goal of 5G networks is to enhance the user experience and the applications of services through the provision of infrastructure and coverage for vehicles with heterogeneous mobility, as well as by achieving very low latency, huge data volumes, and extremely high availability [98]. In addition, SDN improves the suggested system to aid in a network-slicing architecture for mobility management in HetNets slices within edge clouds. Further, we want to investigate and create ways to acquire various slice mobility patterns in edge clouds [27,131]. There is a lot of research on SDN related to complementing strategies for MEC operations, and the advantages of SDN satisfy these needs. The computational performance of reinforcement learning-based IoT devices may be significantly enhanced with an SDN-based MEC architecture [124].

5.4. Deep learning

One area of AI that focuses on teaching computers to do tasks on their own is deep learning [132]. Furthermore, deep learning employs methods based on artificial neural networks and advanced technology to resolve intricate issues. The basic idea is to integrate network deep learning with KPIs to manage network traffic and handover using a deep learning algorithm. The user device data and mobility network key performance indicator determines the appropriate parameter. Deep learning algorithms have been suggested as a potential solution in much research. However, many complaints include calculations, poor processing, and UE memory needs [133,134]. These challenges in applying deep learning in 5 G networks and B5G technology are being addressed through ongoing research and development, providing reassurance about the progress in this field. In deep learning (DL), a subset of machine learning, neural networks automate the quality extraction process from massive datasets; these features are then used to categorize inputs, make judgments, or produce new data. The IoT, AR, VR, automotive networks, and smart cities are just a few of the 5G verticals that will benefit from MEC applications and the recently defined application standard for deep learning in 5G networks. With the help of beyond-fifth-generation (B5G) technology, AR apps are solving the problems of low latency and highly dependable connections. B5G has great potential since it can bring AI closer to consumers, provide edge caching capabilities, and enable MEC. Researchers are investigating a deep reinforcement learning offloading model to enhance decision-making about AR offloading and gain a more comprehensive understanding of utilizing B5G network resources.

According to Refs. [135–137], this offloading approach simplifies computing. With data transfer from MAR to a server in the cloud, deep learning reliably forecasts the next gNB in 6G. Conditional handover (CHO) allows intelligent decision-making in the same challenging circumstances and avoids improper preparatory events. The performance evaluation results show that the predicted PCHO is 98.8 percent more accurate. A low-latency, dependable, and quick wireless network is essential for augmented and virtual reality [103,138].

5.5. Dynamic position deployment of UAV

Unmanned aerial vehicles (UAV)-Base Station is an efficient solution to coverage issues brought on by the overload of variations that correctly improve the location of UAVs, also known as drones. Identifying the most suitable position for the UAV-BS is essential to meet the data accuracy requirement and dynamically maximize operator interests [42, 113]. The unique characteristics of UAVs allow them to build communications networks by carrying the BS.

Fig. 5 showcases the use of BS modules as airborne base stations, a solution that addresses the expensive and challenging process of setting up ground-based BS. The evolving research landscape, now increasingly focused on wireless communication in UAV networks, holds immense promise for future development. The strategic placement of UAV base stations and efficient allocation of.

Communication resources, a task of paramount importance, significantly enhances the effectiveness and expansion of UAV communication networks. Much research is being conducted on UAV site allocation and communications resource allocation to increase UAV networks' storage capacity and utility. UAVs can significantly improve channel conditions and provide low-cost air-to-ground (ATG) wireless links. Although UAVs have been extensively studied for providing on-demand emergency communications to maximize coverage, their 3-D deployment is also required in dense and high-altitude urban scenarios to improve coverage quality [139,140].

Furthermore, Integrated Sensing and Communication (ISAC) is a cutting-edge technology currently being explored for its potential in 6G wireless networks. It aims to harness the existing wireless infrastructure and spectrum resources to provide a blend of unique sensing and communication capabilities. One of the practical applications of ISAC is in the monitoring and control of network-connected unmanned aerial vehicles (UAVs), especially those operating at low altitudes. ISAC signals

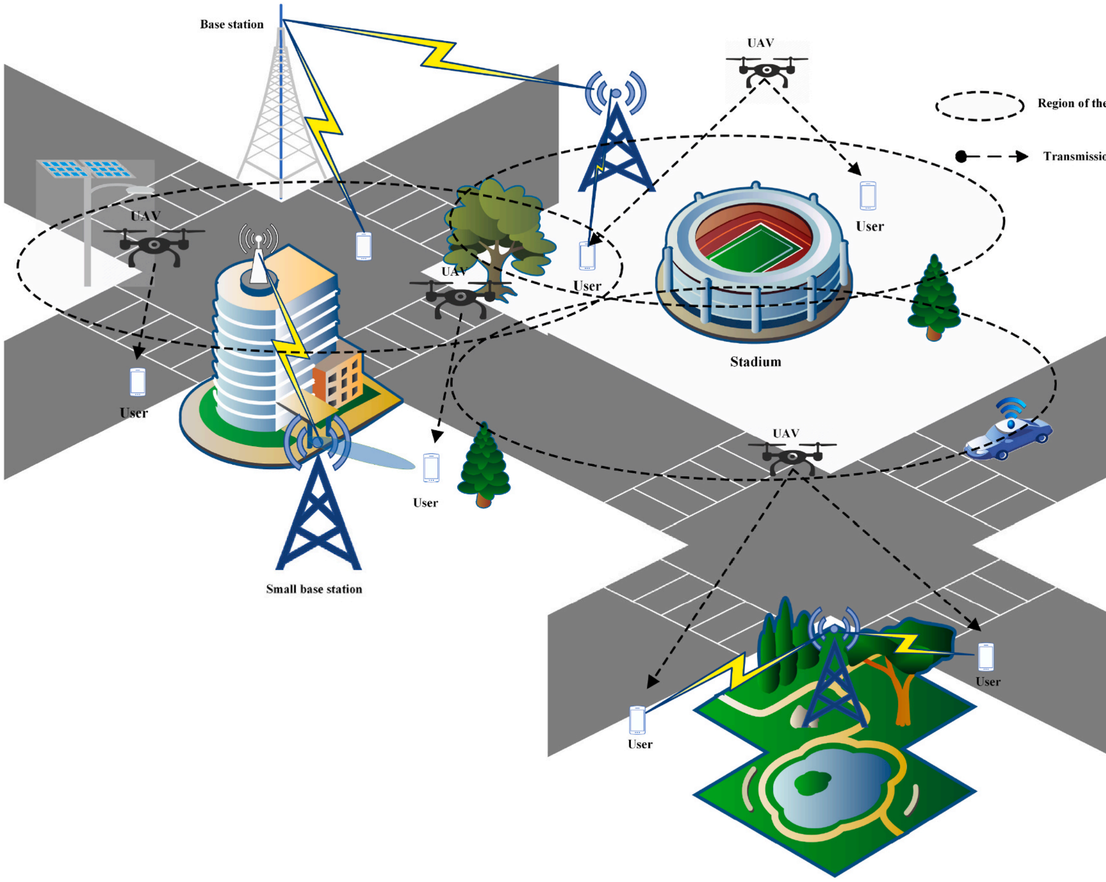

Fig. 5. Delivering UAV-BS in high-traffic areas, including stadiums, deflects cell congestion, improving the quality of service and users' experience.

in this context enhance communication efficiency by accurately predicting beam trajectories. In addition, the utilization of the reflected UAV signals can lead to enhanced cellular coverage through optimal management of resources as well as the path of the UAVs [141]. However, the solid UAV ground Line of Sight (LoS) link always interferes with the terrestrial users and BS. LoS proposes new solutions for cooperative interference management and

Control in the heterogeneous ISAC networks. The concept of FL, which stands for Federated Learning, can be implemented per domain for numerous objectives, such as optimizing resource allocation, improving network reliability, and reducing interference. As per the global aggregated models, the UAVs can predict the network resources, system failures, and the state of the communication link and change their course, location, and data path routing. The local models can be modified to bring the UAVs into the FL process [142].

UAVs adjust their placement, trajectory, and energy allocation based on user mobility and traffic distribution. Therefore, as mentioned in the previous section, A2A communications must be studied in order to provide UAVs with information about user mobility. Thus, the UAVs can adjust their mobility accordingly to improve the users' A2G communication quality and QoE. Moreover, managing handover and optimizing resource allocation has been converted into a machine-learning problem. A solution has been proposed using a reinforcement learning algorithm.

Deploying drones using deep reinforcement learning (DRL) protects against redundant handover decisions to maintain link stability. The DRL framework and the PPO algorithms were used together in the neural network to successfully send and receive decisions about which vehicle to hand over and the strength of the signal. Relevant data were compared based on the received signal strength indication (RSSI) KPIs for maintaining HOs above −70 dBm with 90 % accuracy for trajectory [143–145]. In this scenario, we focus on the UAV mobility environment to improve the wireless transmission in the city and cover all specifications in the handover mobility management for the ground user.

6. Conclusion

Mobile edge computing facilitates the service migration from the cloud servers to the network edge, decreasing latency and alleviating network overload. This research, of significant importance, focuses on the views and thoroughly studies mobility awareness with mobile edge computing in 6G networks. The integration between mobility awareness and MEC was examined, encompassing its fundamental throughput, practical uses, and associated challenges. This survey provides a comprehensive literature review of the implementation of mobile edge computing in 6G, enabling mobile users' applications during the migration of services from one edge node to another. Subsequently, this literature survey introduces a comprehensive explanation for each subsequent phase of mobility applications and solutions. However, this article thoroughly analyzes MEC's implementation, processing capabilities, and mobility-aware aspects, which will have an essential influence on commercializing 6G networks using end-user applications. Next, we extensively analyze the technological obstacles assigned to mobile edge computing and mobility awareness. The existing models focus on mobility awareness, as shown in Table 3. We extensively study the research challenges following reliability and mobility, service migration, task offloading, and edge caching. Furthermore, we are discussing the prospective research direction of mobility awareness concerning mobility management, encompassing concepts such as ML, software-defined networks, and dynamic resource orchestration. Hence, it is imperative to research the future interaction of mobility awareness and 6G technology.

CRediT authorship contribution statement

Soule Issa Loutfi: Writing – review & editing, Writing – original draft, Conceptualization. **Ibraheem Shayea:** Supervision. **Ufuk Tureli:** Supervision. **Ayman A. El-Saleh:** Supervision. **Waheeb Tashan:** Supervision.

Declaration of competing interest

The authors named below declare that they do not possess any identifiable conflicting financial interests or personal ties that may have seemed to exert an impact on the research presented in this study.

Data availability

No data was used for the research described in the article.

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