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Mobile Edge Computing Beyond 5G/6G With Introduction to MEC-NIB in Battlefield

Dixit Bali
Birla Institute of Technology and Science, Pilani
India

Anshu Garg
Birla Institute of Technology and Science, Pilani
India

***Abstract*—With the development of 5G (Fifth Generation) wireless Technology, the dynamics of computation are changing. Mobile Edge Computing (MEC) is widely regarded as a crucial constituent of 5G networks as it has the potential to considerably enhance the functionality and performance of mobile applications. Implementation of Mobile Edge Computing in defence forces requires a deep knowledge of Mobile Edge Computing architecture, components, and deployment scenarios that are discussed subsequently in this paper. Mobile Edge Computing (MEC) can offer defence forces considerable advantages by facilitating sophisticated computing capabilities by moving closer to the end-users, reducing latency, enhancing bandwidth efficiency, and making new applications feasible that were previously impractical. The paper further focuses on understanding MEC beyond 5G/6G with potential use cases in military domain. The proposed model of MEC-NIB is also discussed in this paper which will give close to zero latency in the battlefield. Finally the paper concludes by introducing the future Challenges and Opportunities that MEC beyond 5G/6G entails for mobile computing and networking.**

***Index Terms*—Mobile Edge Computing, MEC beyond 5G/6G, MEC in Defence Forces, MEC-NIB, Military use cases of MEC-NIB, MEC Challenges and Opportunities**

I. INTRODUCTION

MEC (Mobile Edge Computing) is a network architecture that enables data processing and storage at the edge of the network, closer to end-users and devices. MEC is an innovative approach that facilitates IT service delivery and cloud computing capabilities at the edge of the network, particularly within the radio access network and in immediate proximity to mobile subscribers [1]. This can help reduce latency, improve network efficiency, and enable new use cases and applications. 5G/6G refers to the next-generation cellular networks that promise higher data rates, lower latency, and more devices connected to the network. However, these networks have their limitations such as network congestion, security and privacy concerns, and scalability issues. The purpose of this research paper is to explore how MEC can go beyond the limitations of 5G/6G and provide new opportunities and use cases for theDefence Forces. The paper will discuss MEC beyond 5G/6G, the challenges and opportunities of MEC beyond 5G/6G, and military use cases.

II. COMPONENTS AND ARCHITECTURE OF MEC

A.Components of MEC

The components of the MEC architecture include edge servers, edge gateways, and edge devices.

- Edge Servers These are responsible for processing data and running MEC applications and services.
- Edge Gateways This provides connectivity between edge devices and the edge cloud. The technology used in an edge gateway typically includes software-defined networking (SDN) and network functions virtualization (NFV). SDN is used to create a virtualized network, while NFV is used to virtualize network functions such as firewalls, load balancers, and routers. Additionally, edge gateways may utilize cloud computing [2] technologies such as containers and serverless computing.
- Edge devices These are the devices that are deployed at the edge of the network, such as sensors, cameras, and other IoT devices. These devices collect and process data in real time, allowing for faster and more accurate decision-making.

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B. Network Architecture with MEC

The architecture of MEC consists of three layers: the radio access network (RAN), the edge cloud, and the core network.

- Radio Access Network The RAN is responsible for providing connectivity between the end users and the edge cloud
- Edge Cloud It provides the processing power and storage necessary for MEC applications and services.
- Core Network This is responsible for managing the overall MEC infrastructure and providing connectivity to other networks.

C. MEC Framework: ETSI

The ETSI MEC (Mobile Edge Computing) framework is a standardized architecture for deploying MEC services. The framework was created by the European Telecommunications Standards Institute (ETSI) to define a standardized approach to MEC deployment, with a focus on interoperability and scalability. The ETSI MEC framework is designed to enable interoperability between devices and applications, ensuring that MEC services can be deployed and managed in a consistent and predictable manner. The framework provides a powerful management environment for MEC resources and applications, enabling organizations to rapidly deploy and manage MEC services. In 2014, European Telecommunications Standards Institute (ETSI) developed a MEC technical white paper [3], and a new Industry Specification Group was established in ETSI to produce spe

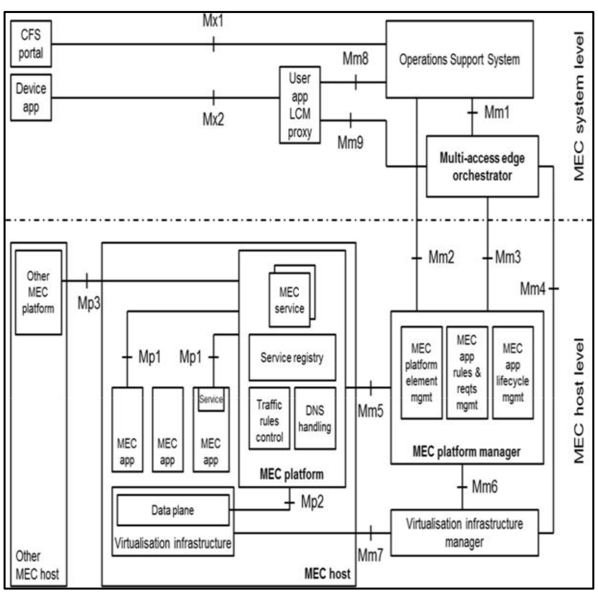

Fig. 1. MEC Architecture by ETSI, (Fabio Giust, NEC Laboratories Europe, Germany, Xavier Costa-Perez, NEC Laboratories Europe, Germany, and Alex Reznik, Hewlett Packard Enterprise, US, IEEE 5G Tech Focus: Volume 1, Number 4, December 201

The ETSI MEC framework [17] consists of several key components:

1) MEC Platform: The MEC platform provides a computing infrastructure that is located at the edge of the network, close to the end-user or device. The MEC platform includes servers, storage, and networking equipment, as well as soft- ware platforms such as Kubernetes and containers.

2) MEC Applications: MEC applications run on the MEC platform and provide services to end-users or devices. MEC applications can include video surveillance, traffic management, emergency response, and other services.

3) MEC Host: The MEC host is the physical or virtual infrastructure that hosts the MEC platform and MEC applications.

4) MEC Management: MEC management provides a range of features for managing MEC resources and applications. This includes functions such as resource allocation, load balancing, and auto-scaling.

5) MEC APIs: MEC APIs provide a standardized way for applications to interact with the MEC platform. APIs include interfaces for accessing MEC services, managing MEC resources, and configuring MEC applications.

6) MEC Security: MEC security provides robust security measures to protect against unauthorized access, data breaches, and other security threats. This includes measures such as encryption, access control, and intrusion detection and prevention systems.

III. MEC BEYOND 5G/6G

MEC (Mobile Edge Computing) beyond 5G/6G refers to the evolution of MEC beyond the current 5G and future 6G

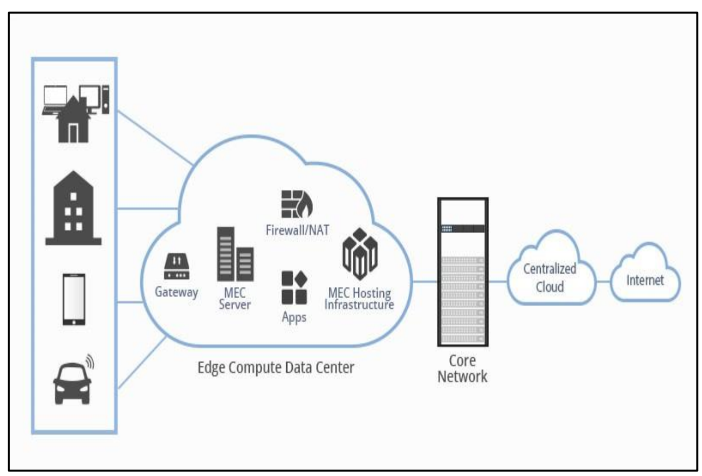

Fig.2. MEC Network Topology, (https://www.fiberopticshare.com/what-is- multi-access-edge-computing.html)

networks, to enable more advanced and innovative use cases and applications.

The integration of edge intelligence plays a crucial role in enabling 6G networks [8]. Several studies have proposed future directions for 6G, although it is still in its nascent stage [4]- [5]. MEC beyond 5G/6G could involve the integration of MEC with other emerging technologies, such as artificial intelligence (AI) [19], machine learning (ML), blockchain, and Internet of Things (IoT), to enable more intelligent, autonomous, and secure edge computing.

A. Advantages of MEC beyond 5G/6G

MEC (Mobile Edge Computing) beyond 5G/6G has several advantages over traditional edge computing and MEC in 5G/6G networks. Some of the key advantages include:

1) Enhanced performance: Enhanced network performance can be achieved by optimizing the allocation of resources, such as spectrum, computation, and power within the network [9]. With the use of advanced technologies such as AI, ML, and IoT [7], more intelligent, autonomous, and responsive edge computing can be enabled.

2) Greater Scalability: By the use of cloud-native architectures and technologies, more efficient resource utilization and deployment and more seamless integration with existing cloud infrastructure [16] can be enabled.

3) Improved Security and Privacy: By leveraging advanced security technologies like blockchain [13], it becomes possible to enhance the security and transparency of data sharing and access control. With the assistance of emerging paradigms, such as federated learning [10], MEC will significantly boost data privacy in the analysis of data for 6G applications.

4) Enabling new use cases: MEC advancements beyond 5G/6G open the door to novel and innovative use cases and applications. These include autonomous systems, smart cities, industrial automation, and telemedicine, expanding the potential beyond what current MEC solutions can offer.

5) More efficient resource utilization: MEC’s advancement beyond 5G/6G holds the promise of optimizing resource utilization [21] and enhancing energy efficiency in edge computing. This is achieved through innovative technologies such as edge caching, dynamic load balancing, and power management.

IV. USE CASES OF MEC IN BATTLEFIELD

A. Situational Awareness

MEC can play a significant role in enhancing situational awareness in the military. With MEC, real-time data can be collected and processed at the network edge, allowing for quicker decision-making and response times. Some use cases of MEC in situational awareness for the military include:

1) Sensor Networks: MEC can support sensor networks to detect [20] and process information from various sources, such as radar, sonar, and video surveillance systems. This enables real-time data analysis, improving the accuracy and speed of threat detection.

2) Unmanned Aerial Vehicles (UAVs): MEC can be used to enable UAVs to operate autonomously in the field. A possible MEC architecture is the utilization of UAVs for assistance, where a UAV roams around a designated area, acting as a server for computing tasks of mobile users or serving as a relay to offload computation tasks to an access point [11]. In research, [12] the computation tasks of mobile users were offloaded to a terrestrial BS with the help of a UAV acting as a relay. With edge computing capabilities, UAVs can make decisions based on real-time data, allowing them to respond to changing environments and avoid collisions.

3) Augmented Reality (AR): MEC can support AR technologies to enhance situational awareness for soldiers on the ground. With AR, soldiers can overlay real-time information, such as maps and target locations, onto their surroundings, improving their understanding of the battlefield.

4) Communication Networks: MEC can support reliable and secure communication networks for military operations. With MEC, communication networks can be decentralized and distributed, improving their resilience to attacks and failures.

B. Augmented Reality (AR)

Augmented Reality (AR) is another potential use case for MEC in military operations. AR technology can overlay digital information onto real-world environments, providing soldiers with enhanced situational awareness and allowing them to access critical information quickly and easily. [18]

By leveraging MEC, AR applications can offload the heavy computational load required for AR processing to the edge, reducing latency and improving response times. This can be particularly valuable in military operations, where split-second decisions can have life-or-death consequences.

For example, soldiers could use AR applications to identify enemy positions, view real-time updates on the battlefield, and receive mission-critical instructions, all without taking their eyes off their surroundings. By using MEC to process AR data at the edge, soldiers can access this information quickly

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and seamlessly, improving their ability to carry out missions effectively and safely.

C. Communication

MEC can help ensure that military personnel are connected and informed in real-time, which is critical for mission success and personnel safety.

MEC can improve communication in military operations by enabling efficient, low-latency data transfer and processing at the network edge. This is particularly important in battlefield scenarios where communication can be disrupted or delayed due to network congestion or physical barriers.

With MEC, soldiers can access real-time communication tools and applications, such as video conferencing, instant messaging, and VoIP, on their mobile devices. MEC can also provide localized data processing and storage for improved situational awareness and decision-making.

Additionally, MEC can enhance the security and reliability of military communication networks through edge-based encryption and distributed processing. This can help prevent unauthorized access and mitigate the impact of network disruptions or attacks.

D. Autonomous Systems

MEC can also be used in the military for the deployment of autonomous systems, such as unmanned aerial vehicles (UAVs) and unmanned ground vehicles (UGVs) [15]. By utilizing MEC servers located at the edge of the network, these systems can benefit from improved processing power and reduced latency for real-time decision-making.

One of the main advantages of using MEC for autonomous systems is the ability to offload computationally intensive tasks to nearby MEC servers, allowing the systems to operate more efficiently with reduced power [6] consumption. For example, MEC can be used for real-time image processing to improve object recognition and tracking, enabling UAVs and UGVs to navigate autonomously and avoid obstacles.

Moreover, MEC can support the deployment of swarms of autonomous systems, allowing them to coordinate their activities and operate together in a more intelligent and efficient manner. This can be particularly useful in military applications where a large number of autonomous systems are needed to carry out a specific mission or task

V. PROPOSED MODEL FOR 6G: MEC-NIB

(NETWORK IN BOX

MEC Servers are often placed in conjunction with RAN (Radio Access Network). With the upgradation of the network to 6G, the distance between UE and MEC server should be minimized to get real-time computational capabilities with ultra-low latency. This can be achieved by using MEC-NIB (Mobile Edge Computing - Network-in-Box).

MEC-NIB is a portable MEC server that will be attached to the UE. MEC-NIB will be a compact mobile computing system designed to bring the benefits of MEC to remote or isolated locations. MEC-NIB will be parallelly connected to the considerably large MEC Server at RAN to handle high-bandwidth or compute-intensive tasks. Different systems will have individual MEC-NIBs which will in turn process the data at the user location itself providing a faster response and close to zero latency. The device will be typically small enough to be carried by a single person and highly ruggedized to withstand harsh environments.

A compact and ruggedized small portable MEC server could be an advantageous resource for soldiers on the battlefield. It can provide them with state-of-the-art computing capabilities, real-time data analysis, and situational awareness, all in aconvenient and durable package called MEC-NIB.

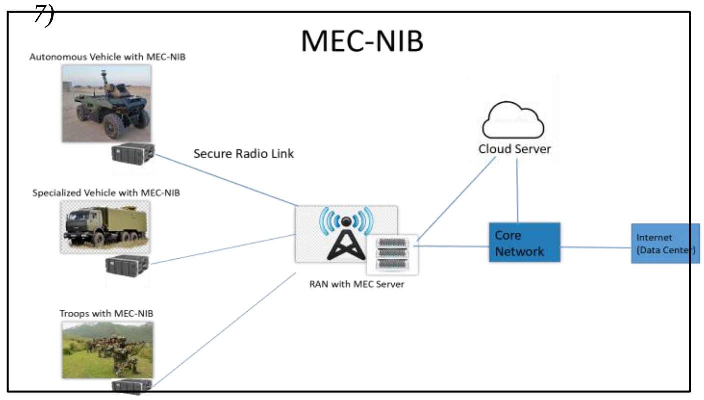

Fig. 3. Proposed Model for MEC Server beyond 5G/6G: MEC-NIB

A. Components of MEC

Components of MEC NIB will entail having all integrated subunits providing greater flexibility and agility in terms of deployment and operation. The basic components of MEC NIB will include:

1) Hardware: The portable MEC server would be built on a compact, ruggedized hardware platform capable of withstanding harsh environments and conditions. The hardware should also be able to operate on battery power for an extended period.

2) Computing resources: The MEC server would consist of computing resources such as CPU, GPU, and memory to provide processing power for the applications.

3) Storage: The MEC server would have local storage to store data and applications. It should also support external storage devices for data storage.

4) Connectivity: The portable MEC server would have multiple connectivity options such as Wi-Fi, cellular, and satellite to connect to the network and communicate with other devices.

5) Security: The MEC server must have built-in security features such as firewalls and encryption to ensure data privacy and prevent unauthorized access.

6) Applications: The portable MEC server would host a range of applications that are specifically designed for military

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8) Sensors: The MEC server may also have sensors integrated into it to collect data on the environment, such as temperature, humidity, and location, to provide situational awareness to the soldier.

B. Latency Computation

The distance, network congestion, and processing time between the MEC server and the UE will all be taken into account when calculating the Total latency for data transmission.

The following components are considered in latency calculations:

1) Propagation Latency: The time it takes for a signal to travel from the sender to the receiver over a communication medium is referred to as propagation latency.

$$Propagation\ Latency = \frac{Distance}{Propagation\ Speed}$$

(2) Transmission Latency: Analyze the size of data being transmitted and the network bandwidth which is available.

$$Transmission\ Latency = \frac{Data\ Size}{Band}$$

purposes such as situational awareness, command and control, and battlefield analytics.

2) Processing Latency: The processing time required at the MEC server depends on the complexity of the computations and the efficiency of the server.

3) Total Latency / Nodal Delay:

$$\text{Total Latency} = \text{Propagation Latency} + \text{Transmission Latency} + \text{Processing Latency}$$

C. Latency Calculation Variations: MEC Server at UE compared to Edge Server

Let distance from the edge to the user is 100 kilometers. Let bandwidth be 1 Gbps, and data size be 1 MB. Let propagation speed be speed of light.

1) MEC Server at Edge:

$$Propagation\ Latency = \frac{100,000\ meters}{3 * 10^8\ m/s}$$
$$= 0.33\ milliseconds$$

$$Transmission\ Latency = \frac{1\ MB}{1\ Gbps}$$
$$= 8\ milliseconds$$

$$Processing\ Latency = 5\ milliseconds$$

$$\text{Total Latency} = \text{Propagation Latency} + \text{Transmission Latency} + \text{Processing Latency}$$

$$Total\ Latency = 0.33 + 8 + 5$$
$$= 13.33\ milliseconds$$

2) MEC Server placed directly at UE, MEC-NIB:

- Propagation Latency: In a tactical operation, the user equipment and the MEC server are in close proximity, resulting in minimal propagation latency. Given the immediate physical vicinity, the propagation latency can be considered negligible. Thus the propagation latency is near zero, as calculations are done locally at the user equipment.
- Transmission Latency: Assume internal communication within the user equipment involves quick exchanges between components or modules. Henceforth, Assume 1 millisecond of Transmission Latency for local communication within the user equipment.
- Processing Latency: During a tactical operation, the user equipment must process data rapidly to support decision-making. Assume 3 milliseconds for local processing considering the complexity of tasks involved in real-time time-sensitive operations.

$$Total\ Latency = 0 + 1 + 3 = 4\ milliseconds$$

3) Observations: The examination of latency in the con- text of Mobile Edge Computing (MEC) deployed at the edge and MEC on User Equipment (UE) presents crucial observations, especially when considering their implications for military operations. The latency measurements distinctly favor MEC at UE, showcasing significantly lower delays. In military scenarios where rapid decision-making and real-time responsiveness are paramount, the proximity of computational resources to the user in MEC at UE translates to near- zero propagation latency and highly efficient local processing. The internal communication within the UE further minimizes delays, rendering MEC at UE a compelling choice for military applications demanding ultra-low latency. In contrast, MEC at the edge, while providing centralized computational capabilities, introduces higher latency due to increased propagation distances. This latency disparity underscores the strategic advantage of deploying MEC directly at UE for military operations, where swift and precise information processing is critical for success. The findings affirm the superiority of MEC at UE in enhancing the responsiveness and performance of military applications, aligning seamlessly with the stringent requirements of mission-critical operations.

D. Requirement of MEC-NIB for Military Operations

Military operations in real-time involve a variety of complex computations across different domains.
These computations often require high-performance computing capabilities, especially in real-time military applications where rapid decision-making is critical. Additionally, the integration of mobile edge computing, as well as advancements in artificial intelligence and machine learning, can enhance the speed and accuracy of these computations in the context of military operations. Following are the scenarios where this MEC-NIB is required and can be actively employed for Military Operations.

1) Geospatial Analysis:

- Calculations related to mapping, terrain analysis, and navigation.
- Geospatial intelligence required for locating targets, understanding the environment and planning movements.

2) Targeting and Fire Control:

- Ballistic calculations for artillery and missile targeting.
- Fire control computations to ensure accurate weapon systems deployment.

3) Communication and Signal Processing:

- Encryption and decryption of communication signals to secure transmissions.
- Signal processing for radio communication and electronic warfare.

4) Surveillance and Reconnaissance:

- Image and video processing for analyzing surveillance data.
- Object recognition and tracking algorithms for identifying potential threats.

5) Logistics and Resource Management:

- Optimization algorithms for planning troop movements and supply routes.
- Resource allocation calculations to ensure efficient use of manpower and equipment.

6) Cybersecurity and Information Assurance:

- Encryption key generation and management.
- Real-time threat detection and response in cyber operations.

7) Human Performance Monitoring:

- Biometric data analysis for monitoring soldier's health and performance.
- Predictive modeling for fatigue management and decision support.

8) Mission Planning and Decision Support:

- Pathfinding algorithms for planning optimal routes.
- Decision support systems that consider various factors in real-time to aid commanders.

9) Aerial and Unmanned Systems Control:

- Flight path planning for drones and unmanned aerial vehicles (UAVs).
- Real-time adjustments to drone missions based on changing conditions.

10) Medical and Casualty Prediction:

- Medical algorithms for assessing casualties and prioritizing treatment.
- Predictive modeling for casualty rates based on the evolving situation.

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VI. CHALLENGES AND OPPORTUNITIES OF MEC BEYOND 5G/6G

MEC (Mobile Edge Computing) beyond 5G/6G presents both challenges and opportunities for the future of mobile computing and networking.

MEC, being an emerging technology, poses several challenges that must be overcome to ensure widespread implementation and acceptance of MEC across different sectors. Some of the primary challenges facing MEC include:

1) Infrastructure: One of the biggest challenges of MEC beyond 5G/6G is the need for significant investment in infrastructure [14], including edge computing resources, 5G/6G networks, and data centers, to support the processing and storage of vast amounts of data.

2) Data Management: Another challenge of MEC beyond 5G/6G is the need for effective data management and security, including data storage, processing, and transmission. This requires implementing appropriate data security and privacy policies and protocols, and ensuring that data is stored, processed, and transmitted securely and efficiently.

3) Edge Security: MEC beyond 5G/6G requires the secure deployment and management of edge resources, including hardware, software, and networks. Security concerns include protecting against edge-based attacks, ensuring the physical security of edge resources, and implementing secure access and authentication mechanisms.

4) Scalability: MEC beyond 5G/6G involves processing and analyzing large amounts of data in real-time. This requires significant computing power [6] and storage capacity, which can be challenging to scale up to meet the increasing demand for data processing and analysis.

5) Reliability: MEC beyond 5G/6G applications require high levels of reliability to ensure uninterrupted service de- livery. This can be challenging due to the complexity of the MEC architecture and the potential for single points of failure.

6) Network Security: MEC beyond 5G/6G also requires securing the entire network infrastructure, including the 5G/6G network, edge resources, and cloud data centers, against a range of potential threats, such as denial-of-service attacks, malware, and unauthorized access.

7) Regulation: Another challenge of MEC beyond 5G/6G is the need for appropriate regulatory frameworks to govern the use and deployment of these technologies, particularly in sensitive areas such as healthcare and finance.

8) Heterogeneous Network Environments: MEC beyond 5G/6G involves the integration of a variety of network environments, such as 5G, Wi-Fi, and satellite networks, which can result in complex interoperability challenges. These challenges include differences in network protocols, data formats, and management systems.

9) Vendor Lock-in: MEC beyond 5G/6G can result in vendor lock-in, where businesses become dependent on a single vendor’s products or services, making it challenging to switch to alternative vendors or platforms.

10) Lack of Standardization: There is currently a lack of standardization in the MEC ecosystem, which can result in interoperability challenges, particularly between different vendors and platforms.

VII. CONCLUSION

MEC beyond 5G/6G can enable faster data processing, reduce latency, and improves the performance of various applications. This research paper provides an overview of MEC (Mobile Edge Computing) in the context of 5G/6G networks, as well as introduces the concept of MEC-NIB which can exponentially reduce the Latency of the MEC Server when deployed for Military use. The analysis of the potential benefits and limitations of MEC beyond 5G/6G including issues related to security and privacy, interoperability, scalability and reliability are also highlighted. Future directions of MEC beyond 5G/6G research should focus on addressing these challenges identified in this research paper.

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