Literature Review and Novel Trends of Mobile Edge Computing for 5G and Beyond

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Abstract

Because of the rapid evolution of communications technologies, such as the Internet of Things (IoT) and fifth generation (5G) systems and beyond, the latest developments have seen a fundamental change in mobile computing. Mobile computing is moved from central mobile cloud computing to mobile edge computing (MEC). Therefore, MEC is considered an essential technology for 5G technology and beyond. The MEC technology permits user equipment (UEs) to execute numerous high-computational operations by creating computing capabilities at the edge networks and inside access networks. Consequently, in this paper, we extensively address the role of MEC in 5G networks and beyond. Accordingly, we first investigate the MEC architecture, the characteristics of edge computing, and the MEC challenges. Then, the paper discusses the MEC use cases and service scenarios. Further, computations offloading is explored. Lastly, we propose upcoming research difficulties in incorporating MEC with the 5G system and beyond.

Keywords: Mobile edge computing; 5G; Computation Offloading.

1. Introduction

The development of wireless communication systems over the past four decades has altered every aspect of our life. Figure 1 demonstrates the wireless communication development history in which capacity, latency, services, speed, and applications varied in each development of wireless communication. Also, each wireless communication development needs various models of computing to handle the network environment, such as mobile cloud computing (MCC), offloading computation, cloudlet, fog computing (FC), and mobile edge computing MEC [1, 2].

The MCC merges wireless communication networks, cloud computing, and mobile computing. Therefore, innovators and service suppliers are enabled to keep up with more complicated implementations by shifting computing abilities and data processing away from portable devices and into the cloud [3]. Nevertheless, due to the restrictions of MCC, which include low scalability and a lengthy propagation distance from the end user to the remote cloud center, mobile applications have significantly higher latency. Also, MCC has concerns with privacy and security, limited storage, and high bandwidth usage [4, 5].

Consequently, many techniques are suggested to overcome the above limitations in MCC, such as cyber foraging or computational offloading where an edge device sends some calculations to a distant ingenious cloud to conserve handling power and energy [6]. Nevertheless, data transfers among public clouds and edge devices via the internet may experience high latency when computation is offloaded to the public cloud. Accordingly, cloudlet-based offloading is presented to solve the previous problem, in which, mobile devices offload computational work to a server with fewer resources that is close to the user through the

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usage of a Wi-Fi access point. Regardless, compared to other cloud computing features, cloudlet is less effective. As a result, its service and resource providers are not scalable.

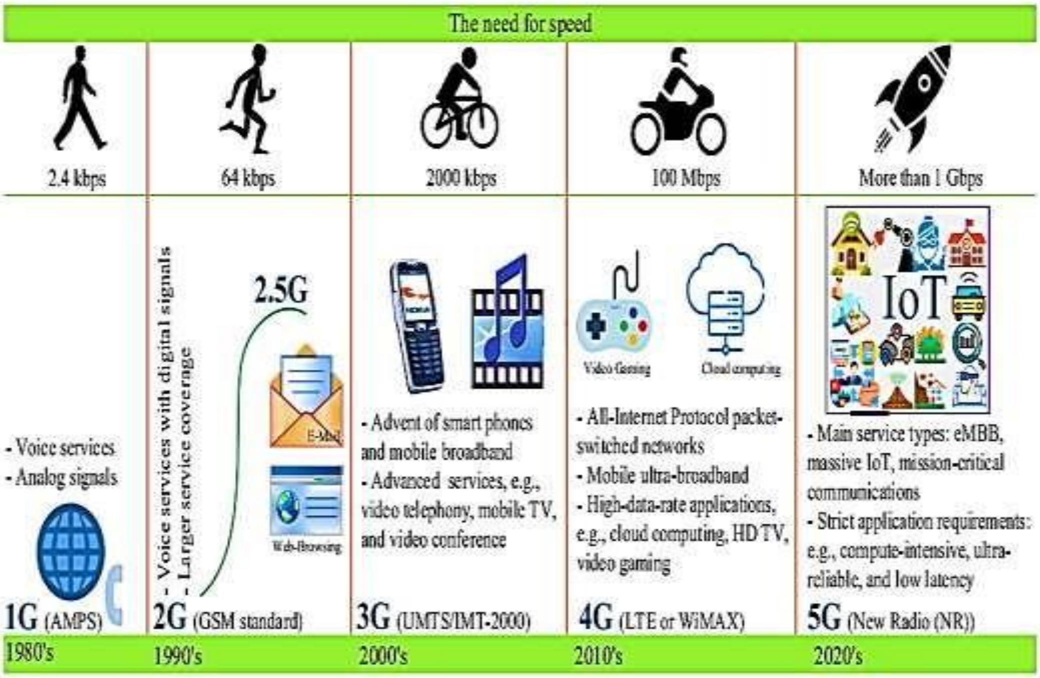

Figure 1: The wireless communication development history [4].

Fog Computing (FC) can solve the previous issues by allowing elastic resources and services for mobile user equipment (UEs). The FC extensively the network architecture in the cloud by presenting a middle layer between the cloud and UEs. Fog servers placed at the network edge make up the middle layer, which is essentially a fog layer. The fog servers are employed to decrease the bandwidth load and energy consumption. Moreover, the cloud's computing power, numerous apps, and services can be used by the fog servers when they are connected to it [7]. The MEC and FC are comparable, and neither has any distinguishing characteristics. Both are closer to UEs and can serve as useful addition to MCC. Also, the MEC and the FC are substantial for implementing the IoT.

Therefore, the MEC is a novel paradigm employed to overcome the challenging issues of MCC. The MEC is a sort of edge computing that furnishes an information technology (IT) advantage environment and cloud computing capabilities at the edge of the mobile network, inside the radio access network (RAN), and near UEs. This technology, which resembles a small data center, can offer services with minimal latency and high availability. But compared to cloud computing, it uses resources for computation and storage that are of poor quality [8].

MEC, which combines elements of IT and telecommunications networking, enables cellular operators to spread their RAN to approved third parties, like application creators and content providers. Therefore, MEC promotes a variety of applications, e.g., Connected vehicles, Augmented Reality/Virtual Reality (VR/AR), robotics, wireless big data analysis, IoT, video streaming analysis, and immerse media. The MCC conveys several advantages such as [9]:

1. Prolonging the battery life by shifting energy-intensive application computations to the cloud.
2. Supplying mobile users with advanced tasks.
3. Providing users with greater data storage capacity.

However, the MCC significantly increases the burden on mobile networks' radio and backhaul, which causes a rise in latency and energy consumption. Due to the fact that the data is routed to a robust set of servers that are located further from the users in the network topology. Therefore, these limitations must

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eliminate to achieve the specific small energy and millisecond-scale latency needed for 5G systems and beyond [10].

Particularly, the paper's contributions can be as succinct as follows:

- Provide a summary of the MEC architectures, characteristics, and challenges.
- Introduce a survey about the MEC use cases and service scenarios.
- Investigate the computation offloading.
- Finally, this paper explores the incorporation of MEC with the 5G System and beyond.

The remaining sections of the paper are arranged as follows: Section 2 presents the MEC architecture. Section 3 explains the MEC characteristics and challenges. Section 4 addresses the MEC use cases and service scenarios. Section 5 investigates the computation offloading. Section 6 studies the incorporation of MEC with the 5G System and beyond. Finally, section 7 concludes the paper.

2. MEC Architecture

The unique architecture of MEC is depicted in Figure 2. The architecture is composed of these three basic elements [5]:

1. Edge devices include all types of network-connected devices, including mobile phones, service subscriber devices, and Internet of Things (IoT) devices.
2. The cloud infrastructure known as the public cloud is accessible over the internet.
3. The MEC servers, which can be organized with wireless APs, are often mini data centers that are built next to each mobile base station by cloud and telecom carriers. Through a gateway, the servers are connected to the data centres' data centers through the internet. In addition to hosting various mobile edge applications (edge health care, smart tracking, etc.), the MEC servers may conduct conventional network traffic control (both forwarding and filtering).

Therefore, the prime purposes of MEC are:

1. The hosting of computationally demanding applications, such as image processing and mobile gaming, at the edge network, enhances the use of mobile resources.
2. Before sending a large amount of data to the cloud, it is optimized.
3. Introducing cloud services to mobile subscribers in the area.
4. Using RAN data to provide context-aware services.

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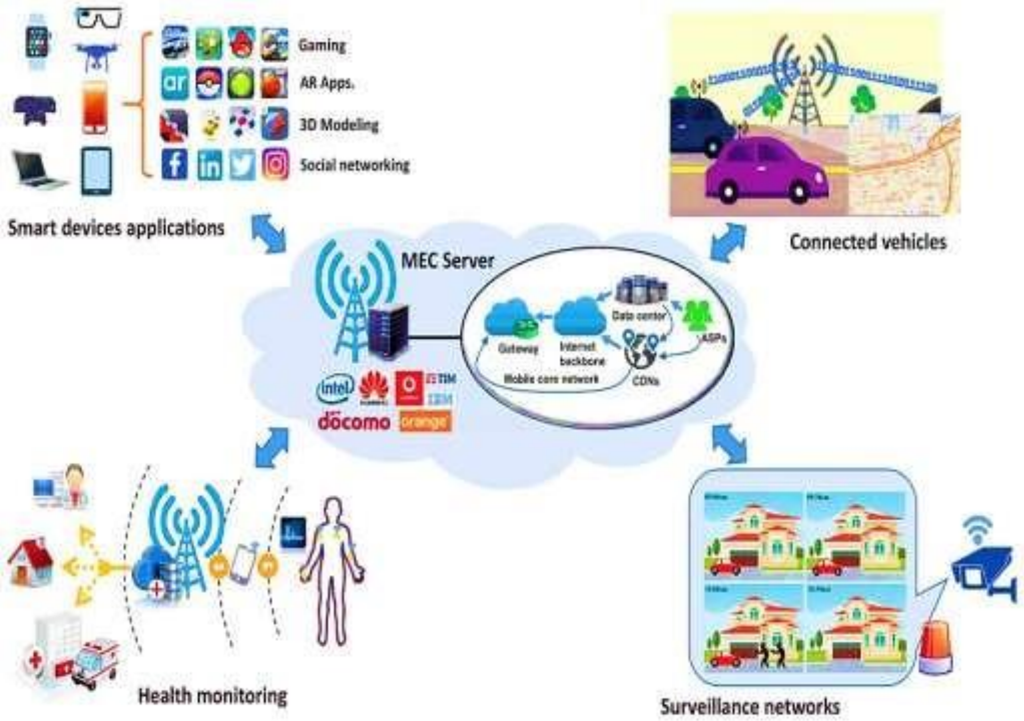

Figure 2: MEC Architecture [5].

3. MEC Characteristics and Challenges

Similarities between cloud computing and edge computing can be seen in various characteristics. However, the characteristics of edge computing that set it distinctive are as follows [11, 12]:

1. Dense Geographical allocation: The edge network at MEC has cloud computing and IT services that are accessible from many different places. Infrastructure that is widely spread geographically makes numerous contributions.
2. Location Awareness: Due to the proximity, MEC may determine the end users' exact locations by using signalling data collected from end users. Therefore, it becomes especially crucial for MEC location-based services.
3. On-premises: MEC has access to local resources and can function in standalone environments (i.e., independently from the rest of the network).
4. Proximity: The location of MEC servers is typically close to where mobile users are.
5. Low Latency: Modern compute-intensive applications may typically be processed in real-time by MEC servers. As a result, MEC offers the possibility of reducing communication and propagation latency, which promotes MEC as a successful enabler for latency-critical 5G applications.
6. Network contextual information: The MEC uses proximity to make distinctions. Therefore, MEC can use its understanding of local contextual data and real-time radio network conditions to enhance the network and QoS.

Because MEC is a vital part of the 5G system and beyond in preparation and deployment, the industry viewers have already recognized three challenges [4]:

1. Managing Distributed Resources: Due to the limited resources, numerous applications, and erratic increase of mobile traffic, resource distribution is a crucial challenge for the success of MEC. Because of the diverse nature of applications, heterogeneous MEC servers, varied user demands and characteristics, and channel link quality, the resource allocation optimization may be multi-objective. As a result, distributed MEC systems cannot benefit from centralized approach. Because it causes backhaul network congestion and has a significant computational complexity and reporting overhead.

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2. Reliability and Mobility: A frequent handover between edge servers may result from user mobility. It suggests that during the offloading of computations, users (such as automobiles) could move to different locations. Therefore, to enable users to access edge servers without any difficulty, mobility management strategies related to both horizontal and vertical mobility should be established. To provide dependable and low-latency services, MEC reliability requires ultra-reliability (99.999%) and extremely low latency of 0.1:1 mSec round-trip time.
3. Coexistence of Distributed MEC and Centralized cloud: Big-data applications can be processed in almost real-time by cloud data centers (Cloud DCs), which can also support many users. However, allotted MEC is strongly preferred to reduce the end-to-end delay brought on by transmission delay and traffic congestion. Therefore, it makes sense to assign big data/latency-critical calculations to dispersed MEC servers while transferring computation-intensive and delay-tolerant assignments to the cloud DC.

4. MEC Use Cases and Service Scenarios:

There are three major use case categories of MEC, relying on the issue to which they are promising and prominent [4, 9, 13, 14]. Figure 3 displays examples of use cases and scenarios for the MEC. The following topics are up for discussion on the various use case categories and significant service scenarios and applications:

1. Consumer-oriented Services:

The end-users should immediately benefit from the consumer-focused services. In public, the MEC benefits users largely through the offloading of computing, which enables the handling of novel emergent applications at the UEs. Web browsers are among the applications that benefit from computing offloading. Additionally, since these tasks need a lot of calculation and storage, face/speech recognition and image/video editing are also appropriate for the MEC. Moreover, online gaming or remote desktop users handling low-latency applications may benefit from the MEC in proximity.

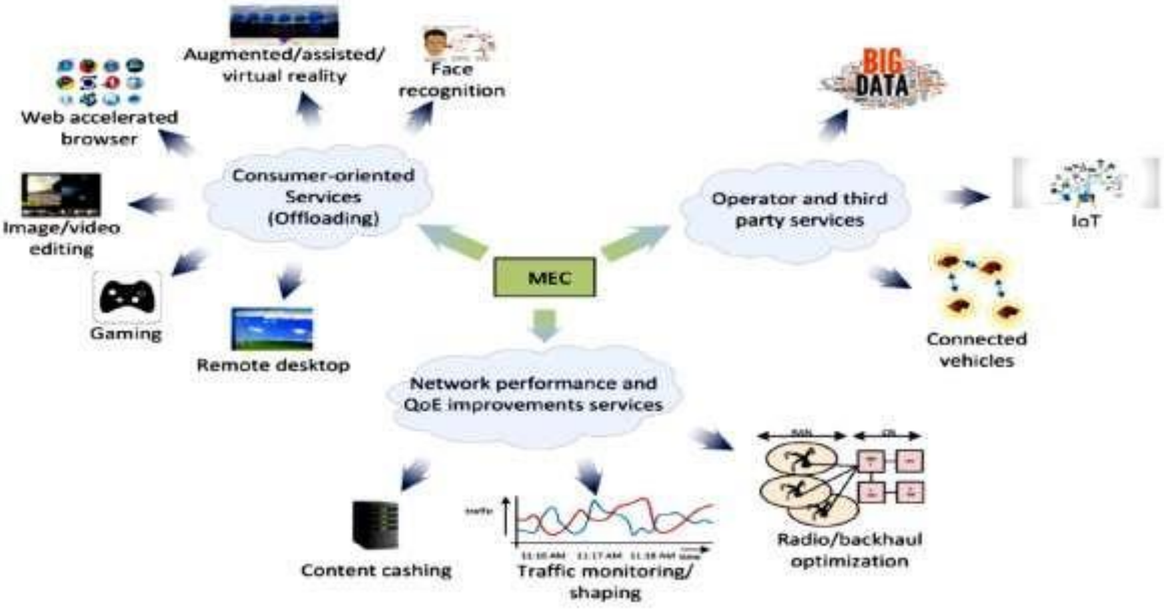

Figure 3: Use cases and scenario examples for the MEC [9].

2. Operator and Third-Party Services:

Examples of use cases that are beneficial to the operator or a third party include:

- Collecting a huge portion of data from the users or sensors.
- Protection and security objectives, like monitoring an area.

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- Using the MEC for IoT and Intelligent Transport Systems (ITS).

3. Services for Improving QoE and Network Performance:

The use cases for optimizing network performance and/or improving the QoE include promoting coordination between radio and backhaul networks, relieving crowded backhaul links via local range caching at the mobile edge, and video delivery optimization using throughput recommendation for TCP.

5. Computation Offloading to MEC:

The computation offloading is one of the key goals of edge computing to overcome the limitations of mobile devices, such as their computational power, battery life, and storage capacity. So, the computation offloading aims to reduce the execution time, decrease the energy consumption at the UE, and find an appropriate trade-off between the energy consumption and the execution delay. Also, it is a challenging to decide when and how to offload the computing assignments. Therefore, a number of techniques are proposed to address this issue in a variety of scenarios, including single-user cases, multi-user cases, and vehicular networks [15, 16, 17, 18, 19]. A choice regarding computation offloading may result in:

1. Local Execution: The UE performs the entire computation locally (i.e., the MEC offloading is not executed).
2. Partial Offloading: A portion of the computation is completed locally, and the remaining portion is offloaded to the MEC.
3. Full Offloading: The MEC offloads and completes the entire computation.

Figure 4 shows the choices for computation offloading.

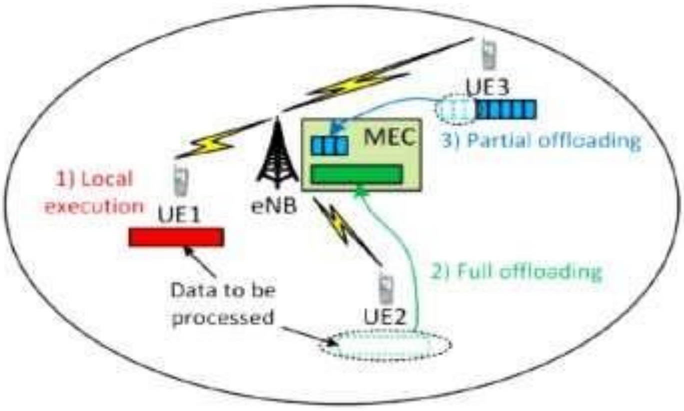

Figure 4: A choice for computation offloading [9].

As a result, there are various categories for computing offloading applications:

1. Offloadability of the application: The application's ability to parallelize and split code or data (i.e., application that may be partially offloaded).
2. Knowledge of the amount of data to be processed: Since the amount of data to be processed is unknown in advance, it is evident that choosing whether to offload calculations might be extremely difficult for continuous-execution applications.
3. Offloadable component dependencies: Application components may be independent of one another or dependent on one another. In the independent situation, all components can be processed concurrently and offloaded. However, when there is mutual dependence, parallel offloading might not be appropriate because the application is made up of sections (components) that depend on one another for information.

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6. Incorporation of MEC with the 5G System and beyond

As was evident in the preceding sections, the MEC has drawn a lot of interest recently because of its ability to lower UE energy consumption and allow real-time application offloading. New architectures and technologies will be implemented in the 5G network to benefit the applications and services of the MEC system. To achieve new features in MEC systems, MEC must be integrated with the 5G system and beyond [4, 20, 21, 22, 23, 24, 25]. As illustrated in figure 5, the following applications, which have a strong connection to MEC use cases, are examples of where MEC is being integrated with 5G technology and beyond:

1) Non-orthogonal Multiple Access (NOMA), millimeter Wave (mm-Wave), and massive multipleinput multiple-output (MIMO).
2) Unmanned Aerial Vehicle (UAV) communications.
3) Energy harvesting (EH) and wireless power transfer (WPT).
4) IoT.
5) Artificial intelligent (AI).
6) Heterogeneous-cloud radio access network (H-CRAN).
7) Machine Learning.
8) Functions virtualization (NFV) and software-defined networking (SDN), and Network Slicing.

Figure 5: The incorporation of MEC with the 5G System and beyond [4].

The NOMA system and MEC technology have been regarded as essential enabling technologies in 5G and beyond [27, 28] because they allow multiple UEs to share the same resources [26]. As a result, the NOMA system and MEC technology combination have many advantages, including supporting massive users, lowering transmission latency, lowering end-user energy consumption, increasing connectivity, boosting spectral efficiency, boosting energy efficiency, boosting computing power, and offering top performance for more complex network scenarios, such as mm-Wave massive MIMO. The following four benchmarks are used to evaluate possible collaborations between NOMA and MEC:

1. Optimization the Joint Resources:

In MEC-NOMA networks, it is necessary to combine computation and communication resources to improve the system's total rate, reduce energy consumption, and reduce latency [29, 30, 31, 32, 33, 34, 35, 36]. In order to reduce latency, the scheduler may need to determine how much computing the user can offload to the MEC server and how much computation may be done locally. In addition, compute capacity (i.e., the

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processing speed of MEC servers or mobile devices) and communication resource (i.e., transmit power) are seen as crucial elements since they help decrease calculation latency. The combined optimization of these variables leads to an important and challenging research issue.

2. Cooperative NOMA-MEC:

By enabling compute offloading to the primary MEC server, the cooperative MEC can be used to improve the connectivity of the NOMA-MEC network [37, 38, 39, 40, 41]. In this case, the mobile device communicates the overlaid signals to the primary MEC server and the assistant MEC server, acting as a relay to assist the MEC server. Also, the cooperative NOMA-MEC can be modified to increase network connectivity when the mobile device is too far from the main MEC server.

3. Coexistence of NOMA-MEC and mm-Wave massive MIMO:

Another scenario to support excellent spectral efficiency and the enormous connection is massive MIMONOMA. NOMA-MEC integration with mm-Wave MIMO-based wireless networks can increase processing capability, boost spectrum efficiency, and cut down on task latency. Accordingly, it is necessary to adopt effective methods of incorporation between NOMA-MEC and mm-Wave MIMO in various studies [42, 43, 44, 45].

4. Low-complexity and online NOMA-MEC schemes:

It is generally recognized that the big challenge to the NOMA's practicality is its computational complexity. The majority of current studies [46, 47] take into account using convex optimization and game theory approaches to resolve resource management issues in NOMA MEC systems, but they often have significant complexity. Therefore, NOMA practicality depends on low-complexity NOMA-MEC approaches. Additionally, the online NOMA-MEC method maximizes long-term system utility (i.e., a measure of throughput and fairness) by optimizing resource allocation and offloading decisions. So, it is essential to create algorithms that are suitable for online execution and are well adapted to the system dynamics.

7. Conclusion

Mobile-edge computing (MEC) has been identified as a promising technology for 5G and beyond because of the rapid progress of intelligent communications. As a result, this article provides a description of MEC technology and examines the trends that will make it a crucial paradigm for 5Gtechnonlogy and beyond. Therefore, MEC architecture is presented first. The characteristics of MEC and its challenges are then discussed. The application cases and service scenarios for MEC are also thoroughly covered in this article. Additionally, the paper provides a summary of computation offloading. Finally, the integration of MEC with the 5G System and beyond is given and discussed.

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References

[1] Yousefpour, A., Fung, C., Nguyen, T., Kadiyala, K., Jalali, F., Niakanlahiji, A., … & Jue, J. P., All one needs to know about fog computing and related edge computing paradigms: A complete survey. *Journal of Systems Architecture*, 98, 289-330, 2019.

[2] Kimovski, D., Mathá, R., Hammer, J., Mehran, N., Hellwagner, H., & Prodan, R., Cloud, fog, or edge: Where to compute. *IEEE Internet Computing*, 25(4), 30-36, 2021.

[3] Dinh, H. T., Lee, C., Niyato, D., & Wang, P., A survey of mobile cloud computing: architecture, applications, and approaches. *Wireless communications and mobile computing*, 13(18), 15871611, 2013.

[4] Pham, Q. V., Fang, F., Ha, V. N., Piran, M. J., Le, M., Le, L. B., ... & Ding, Z., A survey of multiaccess edge computing in 5G and beyond: Fundamentals, technology integration, and state-of-theart. *IEEE Access*, 8, 116974-117017, 2020.

[5] Mao, Y., You, C., Zhang, J., Huang, K., & Letaief, K. B., A survey on mobile edge computing: The communication perspective. *IEEE communications surveys & tutorials*, 19(4), 2322-2358, 2017.

Doi: https://doi.org/10.54216/JAIM.020202
Received: May 21, 2022 Accepted: November 11, 2022

[6] Khan, W. Z., Ahmed, E., Hakak, S., Yaqoob, I., & Ahmed, A., Edge computing: A survey. *Future Generation Computer Systems*, 97, 219-235, 2019.

[7] Peng, K., Leung, V., Xu, X., Zheng, L., Wang, J., & Huang, Q., A survey on mobile edge computing: Focusing on service adoption and provision. *Wireless Communications and Mobile Computing*, 2018.

[8] Kekki, S., Featherstone, W., Fang, Y., Kuure, P., Li, A., Ranjan, A., ... & Scarpina, S. (2018). MEC in 5G networks. *ETSI white paper*, 28(28), 1-28, 2018.

[9] Mach, P., & Becvar, Z., Mobile edge computing: A survey on architecture and computation offloading. *IEEE communications surveys & tutorials*, 19(3), 1628-1656, 2017.

[10] Ismail, A. H., El-Bahnasawy, N. A., & Hamed, H. F., AGCM: Active Queue Management-Based Green Cloud Model for Mobile Edge Computing. *Wireless Personal Communications*, 104(4), 1-21, 2019.

[11] Li, H., Shou, G., Hu, Y., & Guo, Z., Mobile edge computing: Progress and challenges. In *2016 4th IEEE international conference on mobile cloud computing, services, and engineering (Mobile Cloud)*, 83-84, 2016.

[12] Abbas, N., Zhang, Y., Taherkordi, A., & Skeie, T., Mobile edge computing: A survey. *IEEE Internet of Things Journal*, 5(1), 450-465, 2017.

[13] Hu, Y. C., Patel, M., Sabella, D., Sprecher, N., & Young, V., Mobile edge computing: A key technology towards 5G. *ETSI white paper*, 11(11), 1-16, 2015.

[14] Qadir, J., Sainz-De-Abajo, B., Khan, A., Garcia-Zapirain, B., De La Torre-Diez, I., & Mahmood, H., Towards mobile edge computing: Taxonomy, challenges, applications and future realms. *IEEE Access*, 8, 189129-189162, 2020.

[15] Mao, Y., Zhang, J., & Letaief, K. B., Dynamic computation offloading for mobile-edge computing with energy harvesting devices. *IEEE Journal on Selected Areas in Communications*, 34(12), 3590-3605, 2016.

[16] Oueis, J., Strinati, E. C., & Barbarossa, S., Distributed mobile cloud computing: A multi-user clustering solution. In *2016 IEEE International Conference on Communications (ICC)*, 1-6, 2016.

[17] Zhang, K., Mao, Y., Leng, S., Vinel, A., & Zhang, Y., Delay constrained offloading for mobile edge computing in cloud-enabled vehicular networks. In *2016 8th International Workshop on Resilient Networks Design and Modeling (RNDM)*, 288-294, 2016.

[18] Zhan, W., Luo, C., Min, G., Wang, C., Zhu, Q., & Duan, H., Mobility-aware multi-user offloading optimization for mobile edge computing. *IEEE Transactions on Vehicular Technology*, 69(3), 3341-3356, 2020.

[19] Saleem, U., Liu, Y., Jangsher, S., Tao, X., & Li, Y., Latency minimization for D2D-enabled partial computation offloading in mobile edge computing. *IEEE Transactions on Vehicular Technology*, 69(4), 4472-4486, 2020.

[20] Lieira, D. D., Quessada, M. S., Cristiani, A. L., & Meneguette, R. I., Algorithm for 5G resource management optimization in edge computing. *IEEE Latin America Transactions*, 19(10), 17721780., 2021.

[21] Zhou, F., & Hu, R. Q., Computation efficiency maximization in wireless-powered mobile edge computing networks. *IEEE Transactions on Wireless Communications*, 19(5), 3170-3184, 2020.

[22] Wang, X., Han, Y., Leung, V. C., Niyato, D., Yan, X., & Chen, X., Convergence of edge computing and deep learning: A comprehensive survey. *IEEE Communications Surveys & Tutorials*, 22(2), 869-904, 2020.

[23] Wang, F., Xu, J., & Cui, S., Optimal energy allocation and task offloading policy for wireless powered mobile edge computing systems. *IEEE Transactions on Wireless Communications*, 19(4), 2443-2459, 2020.

[24] Tomaszewski, L., Kukliński, S., & Kołakowski, R., A new approach to 5G and MEC integration. In *IFIP International Conference on Artificial Intelligence Applications and Innovations*, Springer, Cham, 15-24, 2020.

[25] Barakabitze, A. A., Ahmad, A., Mijumbi, R., & Hines, A., 5G network slicing using SDN and NFV: A survey of taxonomy, architectures and future challenges. *Computer Networks*, 167, 106984, 2020.

Doi: https://doi.org/10.54216/JAIM.020202
Received: May 21, 2022 Accepted: November 11, 2022

[26] Abd-Elnaby, M., Sedhom, G. G., El-Rabaie, E. S. M., & Elwekeil, M., NOMA for 5G and beyond: literature review and novel trends. *Wireless Networks*, 1-25, 2022.

[27] Kiani, A., & Ansari, N., Edge computing aware NOMA for 5G networks. *IEEE Internet of Things Journal*, 5(2), 1299-1306, 2018.

[28] Du, J., Liu, W., Lu, G., Jiang, J., Zhai, D., Yu, F. R., & Ding, Z., When mobile-edge computing (MEC) meets nonorthogonal multiple access (NOMA) for the Internet of Things (IoT): System design and optimization. *IEEE Internet of Things Journal*, 8(10), 7849-7862, 2020.

[29] Pan, Y., Chen, M., Yang, Z., Huang, N., & Shikh-Bahaei, M., Energy-efficient NOMA-based mobile edge computing offloading. *IEEE Communications Letters*, 23(2), 310-313, 2018.

[30] Mohajer, A., Daliri, M. S., Mirzaei, A., Ziaeddini, A., Nabipour, M., & Bavaghar, M., Heterogeneous computational resource allocation for NOMA: Toward green mobile edgecomputing systems. *IEEE Transactions on Services Computing*, 2022.

[31] Meng, A., Wei, G., Zhao, Y., Gao, X., & Yang, Z., Green resource allocation for mobile edge computing. *Digital Communications and Networks*, 2022.

[32] Liu, J., & Liu, X., Energy-efficient allocation for multiple tasks in mobile edge computing. *Journal of Cloud Computing*, 11(1), 1-14, 2022.

[33] Li, Y., Xu, G., Ge, J., Liu, P., & Fu, X., Energy-efficient resource allocation for application including dependent tasks in mobile edge computing. *KSII Transactions on Internet and Information Systems (TIIS)*, 14(6), 2422-2443, 2020.

[34] Bahreini, T., Badri, H., & Grosu, D., Mechanisms for resource allocation and pricing in mobile edge computing systems. *IEEE Transactions on Parallel and Distributed Systems*, 33(3), 667-682, 2021.

[35] Zhou, Y., Yu, F. R., Chen, J., & He, B., Joint Resource Allocation for Ultra-Reliable and LowLatency Radio Access Networks with Edge Computing. *IEEE Transactions on Wireless Communications*, 21(1), 444-460, 2021.

[36] Chen, X., Cai, Y., Li, L., Zhao, M., Champagne, B., & Hanzo, L., Energy-efficient resource allocation for latency-sensitive mobile edge computing. *IEEE Transactions on Vehicular Technology*, 69(2), 2246-2262, 2019.

[37] Salama, G. M., Ismail, A. H., Soliman, T. A., Hamed, H. F., & El-Bahnasawy, N. A., Congestionaware multiaccess edge computing collaboration model for 5G. *International Journal of Communication Systems*, 33(12), e4446, 2020.

[38] Dong, X., Li, X., Yue, X., & Xiang, W., Performance analysis of cooperative NOMA based intelligent mobile edge computing system. *China Communications*, 17(8), 45-57, 2020.

[39] Li, B., Si, F., Zhao, W., & Zhang, H., Wireless powered mobile edge computing with NOMA and user cooperation. *IEEE Transactions on Vehicular Technology*, 70(2), 1957-1961, 2021.

[40] Ren, M., Chen, J., He, B., Wu, K., Zhou, Y., Xue, X., & Yang, L., Cooperative NOMA-MEC with Helper Scheduling. *IEEE Communications Letters*, 2022.

[41] Yılmaz, S. S., & Özbek, B., Multi-helper NOMA for cooperative mobile edge computing. *IEEE Transactions on Intelligent Transportation Systems*, 23(7), 9819-9828, 2021.

[42] Zhao, C., Cai, Y., Liu, A., Zhao, M., & Hanzo, L., Mobile edge computing meets mm-Wave communications: Joint beamforming and resource allocation for system delay minimization. *IEEE Transactions on Wireless Communications*, 19(4), 2382-2396, 2020.

[43] Fang, F., Wu, B., Fu, S., Ding, Z., & Wang, X., Energy-Efficient Design of STAR-RIS Aided MIMO-NOMA Networks. *IEEE Transactions on Communications*, 2022.

[44] Michailidis, E. T., Miridakis, N. I., Michalas, A., Skondras, E., Vergados, D. J., & Vergados, D. D., Energy Optimization in Massive MIMO UAV-Aided MEC-Enabled Vehicular Networks. *IEEE Access*, 9, 117388-117403, 2021.

[45] Zeng, M., Hao, W., Dobre, O. A., & Poor, H. V., Delay minimization for massive MIMO assisted mobile edge computing. *IEEE Transactions on Vehicular Technology*, 69(6), 6788-6792, 2020.

[46] Cao, X., Liu, C., & Peng, M., Energy-efficient mobile edge computing in NOMA-based wireless networks: A game theory approach. In *ICC 2020-2020 IEEE International Conference on Communications (ICC)*, 1-6, 2020.

Doi: https://doi.org/10.54216/JAIM.020202
Received: May 21, 2022 Accepted: November 11, 2022

[47] Xu, C., Zheng, G., & Tang, L., Energy-aware user association for NOMA-based mobile edge computing using matching-coalition game. *IEEE Access*, 61943-61955, 2020.

Doi: https://doi.org/10.54216/JAIM.020202
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