A Systematic Exploration of Edge Computing-Enabled Metaverse

Chaogang Tang, *Member, IEEE,* Huaming Wu, *Senior Member, IEEE*, Ruidong Li, *Senior Member, IEEE*, Chunsheng Zhu, *Member, IEEE* and Joel J. P. C. Rodrigues, *Fellow, IEEE*

***Abstract*—Metaverse is a concept that aims to create a virtual-reality space where users can engage in social and communication activities. This virtual world is expected to be enabled by a number of key technologies, including edge computing. However, the specific details of how edge computing can boost the development of metaverse still require further investigation, as current literature does not provide sufficient explanations. In this article, we aim to systematically explore the impact of edge computing on the development of metaverse. Firstly, we provide an overview of the architectural design of a metaverse that incorporates edge computing. Next, we delve into the role of edge computing in the metaverse by addressing questions such as why and how it can enhance the virtual world. A use case is then presented to demonstrate how metaverse tasks are offloaded and executed in edge computing-enabled metaverse. Finally, we address some of the challenges associated with this field and outline potential directions for future research.**

***Index Terms*—Metaverse; Edge computing; Task offloading; Resource allocation; Digital twins.**

I. Introduction

THE concept of the metaverse has gained significant attention in both industry and academia, with 2021 being recognized as the "year of the metaverse". The metaverse seeks to create a virtual-reality environment in which users can "live" through customized digital avatars [1]. In this shared digital space, users can engage in communication, socialization, and other daily activities, similar to those in the physical world. The rapid development of metaverse largely benefits from recent advancements in digital twins [2], immersive technologies [3], edge computing, blockchain, and machine learning.

These technologies serve as the cornerstones of the metaverse, and are depicted and discussed in Fig. 1. Digital twins serve as virtual representations of real-world entities, and can powerfully model the physical world by offering digital counterparts within the metaverse. Immersive technologies, encompassing augmented reality (AR) and virtual reality (VR), commonly referred to as extended reality (XR), offer users a deeply immersive experience by means of three-dimensional (3D) rendering. For instance, users engaging with these immersive technologies can vividly experience the serene retirement life of Thanos after the finger snap, that is, sitting on the porch of an unvarnished cottage and gazing out at the magnificent landscape on an alien planet, as described in the science-fiction blockbuster *Avengers: Infinity War*.

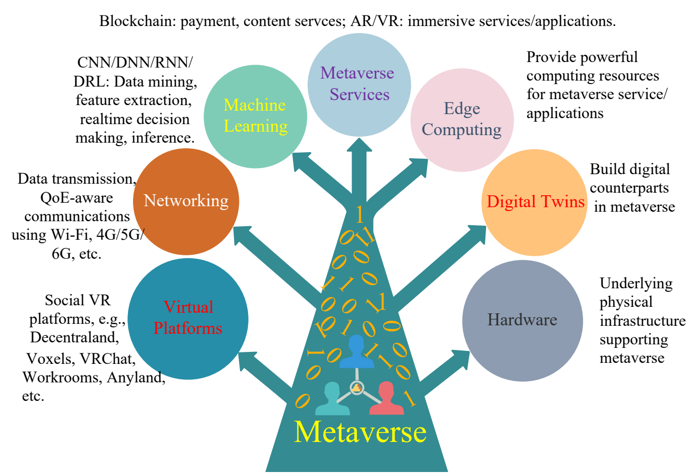


Fig. 1: Enabling technologies for the metaverse.

The metaverse, igniting the public's unprecedented passion, has become the talk of the town in the past two years, even though a unified definition for the metaverse is still under debate. However, a wide consensus has been achieved that we are still in the early stage of the metaverse [1]. It is generally understood that the creation of digital twins is the first phase in the development of the metaverse [4]. To a certain degree, the metaverse can be regarded as an extension of digital twins, by moving the focus from primal product research and development and industrial manufacturing to human-involved communication, collaboration, and socialization. The metaverse, as a vast and complex space that encompasses both physical and virtual worlds, has actually incorporated human, social, economic, and ecological factors, extending far beyond the realm of XR games.

A. Resource Provisioning Related Issues for Metaverse

In view of the unparalleled prospects of the metaverse, numerous endeavors have been dedicated to the creation of various metaverse platforms, services, and applications.

C. Tang is with the School of Computer Science and Technology, China University of Mining and Technology, Xuzhou 221116, China (e-mail: cgtang@cumt.edu.cn).
H. Wu is with the Center for Applied Mathematics, Tianjin University, Tianjin 300072, China. (e-mail: whming@tju.edu.cn).
R. Li is with the Institute of Science and Engineering, Kanazawa University, Kanazawa 920-1192, Japan (e-mail: liruidong@ieee.org).
C. Zhu is with the College of Big Data and Internet, Shenzhen Technology University, Shenzhen 518118, China (e-mail: chunsheng.tom.zhu@gmail.com).
J. Rodrigues is with COPELABS, Lusófona University, Campo Grande 376, 1749-024 Lisbon, Portugal (e-mail: joeljr@ieee.org).
(Corresponding author: Huaming Wu)

Nonetheless, due to the nascent stage of the metaverse, there are still several unresolved issues regarding interaction, computation, ethics, privacy, etc.

1) Among all the have-to-be-addressed issues, computing resource provisioning might be the most important and urgent one, especially when users pursue a real-time interactive high-resolution 3D rendering in the virtual space. This process requires powerful computing capabilities to guarantee ultra-low latency for the metaverse services. Although edge computing is considered to be one of the key enablers for the metaverse, state-of-the-art metaverse services and applications are still rooted in cloud-based physical infrastructure. Avatar physics emulation and graphics rendering computation in the cloud sometimes cannot satisfy the quality of experience (QoE) of users, owing to the huge amounts of data transmission via the backbone networks.
2) A variety of edge devices in edge computing may exhibit significant differences in their computing, storage, and networking capabilities. On the other hand, the metaverse requires enormous computing resources for various metaverse applications/tasks processing. In this context, it is challenging to select which and where to deploy edge devices to meet the requirements of metaverse services such as ultra-reliable low response latency, ultra-high-speed data rates and energy-efficient computation undertaking. It is advisable that the capabilities of edge devices in computing, storage, and networking can match up to the quality of service (QoS) from the perspective of metaverse service providers (MSP) and the QoE from the perspective of metaverse users.
3) Battery-embedded IoT devices deployed for sensing data can restrict cost-effective metaverse deployment, considering short life spans, manual maintenance, infrequent data transmission, and possible environmental harm. It goes against the concept of a low-carbon economy that advocates efficient energy usage and clean energy development. Hence, it is crucial but challenging to supply IoT devices with sustainable and cost-effective energy. Green edge computing, using energy harvesting (EH) technologies, can provide ubiquitous green computing for IoT devices in a self-sustainable fashion. For instance, leveraging harvested off-grid green energy, edge devices can not only power themselves but also supply energy for IoT devices via various wireless power transfer (WPT) technologies.

B. Contribution and Organization

Given the potential benefits of reduced latency, the investigation of edge computing for the metaverse is a worthwhile endeavor. In this article, we perform a systematic exploration of edge computing for the metaverse. The primary contributions of this article are outlined as follows:

- We provide an architectural overview of edge computing-enabled metaverse, and further explore in depth the role of edge computing in enhancing the immersive experiences within the metaverse. This includes addressing the interrogation of why and how edge computing can boost these experiences.
- Given the performance difference of edge devices with regard to computing, caching, and networking capabilities, we categorize edge devices to better support the variability and flexibility of various metaverse applications and services.
- By highlighting the current challenges and potential opportunities in the edge computing-enabled metaverse, this study aims to shed light on future research directions in this field.

The rest of this article is organized as follows. Some literature focusing on metaverse is investigated. Then, the architecture of edge computing-empowered metaverse is proposed, followed by the in-depth exploration of edge computing for the metaverse. In addition, use case studies and performance evaluations are presented, respectively. In the end, some conclusions are drawn.

II. Literature Investigation

There is an increasing growth in scholarly endeavors revolving around the metaverse with regard to the design of architecture, communication, and applications.

Cheng *et al.* [1] discussed the metaverse in detail. For example, they shared the attitudes of high-tech companies towards the metaverse, presented their own vision of the metaverse, and finally introduced several VR platforms. Wang *et al.* [4] conducted research on digital twins in cyber-physical systems (CPS) and cyber-physical-social systems (CPSS), as well as their relationships to Decentralized Autonomous Organizations (DAO) and the metaverse. Specifically, they introduced a novel concept of DAO-based decentralized autonomous metaverses (DeMetaverses) and provided an in-depth analysis of the concept, hoping to transform the current world into a dreamy society that is not only secure in the cyber world but also safe in the physical world.

In view of the diverse types of metaverses, Kshetri *et al.* [5] proposed a typology of metaverse that categorizes them into two main types, namely, 2D metaverse and 3D metaverse, and further classifies them as either centralized or decentralized. In addition, they also suggested several technologies that can be incorporated into the metaverse to cater to different groups of metaverse users. Kirkpatrick [6] gave his own definition of the metaverse, discussed some applications that could benefit from the metaverse, and looked forward to potential technological achievements that could advance the development of the metaverse.

In [7], a comprehensive survey was undertaken to examine the potential application of metaverse technology in the healthcare industry. The study delves into technical challenges and possible solutions, and identifies several open issues and challenges that need to be addressed in the future.

The aforementioned works primarily focus on the metaverse architecture design and application exploration, overlooking the crucial role of edge computing as a key enabler for the

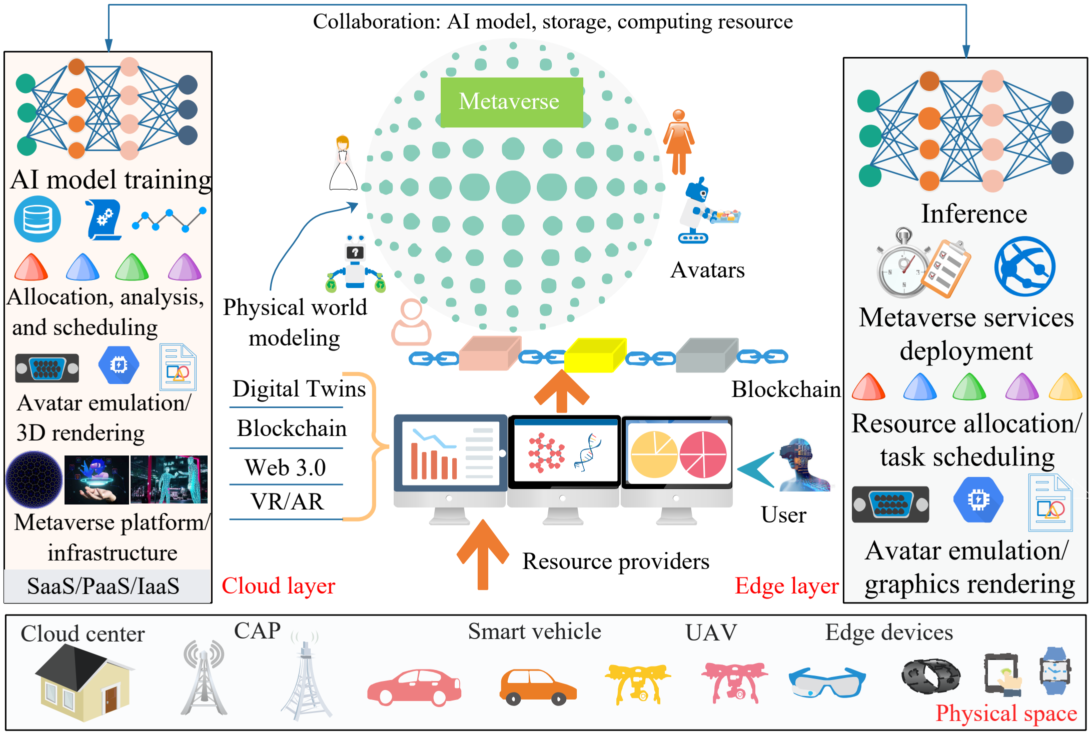


Fig. 2: A typical architecture of edge computing-empowered metaverse.

metaverse. Indeed, this aspect has received limited attention in the existing literature [8]. In [9], edge computing is applied to the metaverse system. A virtual service provider gathers data using UAVs and offloads it to the edge computing platform which is responsible for DTs updating. Karunarathna *et al.* [10] explored the feasibility of realizing metaverse through 5G and beyond 5G technologies, while briefly discussing the role of edge computing in facilitating such realization. However, they failed to delve into the role of edge computing in enhancing the immersive experiences within the metaverse, such as why and how edge computing can boost these experiences. As a contrast, we endeavor to elucidate the ways in which edge computing can enhance these experiences, and further classify edge devices to better accommodate the variability and adaptability of diverse metaverse services.

III. Edge Computing-Empowered Metaverse

A. *Edge Computing with Significant Benefits*

The driving force behind edge computing is the startling rise in a wide variety of applications and tasks that not only require masses of computing resources but also have strict latency requirements. For instance, various XR tasks require computing resources for graphics rendering and high bandwidth for a real-time interactive response. Therefore, cloud computing, provisioning computing resources in remote cloud centers that span backbone networks, is sometimes no longer adequate for these requirements. Edge computing reforms existing infrastructures by flexibly integrating communication and computing resources to the network edge, thus making computing, caching, and storage in close proximity to the users.

A generalized hierarchical architecture for edge computing, also termed edge-to-cloud continuum, actually consists of three layers, namely, cloud layer, edge layer, and IoT layer. The cloud layer enables dynamic allocation and elastic expansion of computing, storage, and network resources. This layer is extremely well-positioned for non-real-time decision-making scenarios requiring huge volumes of computing resources, such as complex AI model training, and image processing. The edge layer moves the computing, communication, cache, and storage resources to the network edge from the remote cloud, which demonstrates a huge advantage in reducing latency in comparison to cloud computing. The IoT layer, generating data and tasks, usually exists as the computing resource requestors. Owing to limited computing capabilities and energy supply, computation offloading operations take place in this layer.

B. *Architecture for Edge Computing-Empowered Metaverse*

The integration of edge computing into the metaverse is a logical progression, considering the diverse computing and real-time response demands of various metaverse applications. By incorporating edge computing, the metaverse can benefit from low-latency and cost-effective solutions, ultimately leading to an enhanced user experience. Fig. 2 illustrates a representative architecture of an edge computing-empowered metaverse, which we will briefly outline in the context of the metaverse.

1) Edge Layer: The edge layer consists of a variety of edge devices that can theoretically serve the metaverse. Specifically, in view of the substantial differences in diversity and performance among these devices, they have been classified into three separate categories, namely, Mini-Edge, Micro-Edge, and Macro-Edge.

- **Mini-edge**: It revolves around the metaverse users, and is comprised of high-end IoT devices, such as smart glasses, rings, and phones. The majority of such devices are equipped with multi-core processors, yet their computing resources remain underutilized in most cases. This presents an opportunity for metaverse applications to leverage the surplus capacity of personal edge devices. More importantly, such computational resources can be utilized at no cost.
- **Micro-edge**: It typically includes edge devices with more abundant computing resources than voluntary edges, such as smart vehicles and unmanned aerial vehicles (UAV), as depicted in Fig. 2. Smart vehicles are capable of environment sensing, intelligent decision-making, task execution, and data analysis, giving rise to vehicular fog computing and vehicular edge computing. Meanwhile, onboard computers and wireless communication facilities are deployed at UAVs, which leads to the emergence of aerial edge computing (AEC). Both "edge on the wheels" and "edge in the sky" are worthy of further investigation for the metaverse [11], [12]. In addition to resource provisioning, UAVs can even supply IoT devices with sustainable and cost-effective energy using WPT technologies.
- **Macro-edge**: It aims to provide a range of resources using powerful edge servers, including but not limited to accessible computational access points (CAP), base stations (BS) and roadside units (RSU). These edge servers have strong computing power, large storage, and abundant networking resources. They can alleviate enormous backhaul pressure and lower the response latency. Various metaverse services can be deployed at these edge servers to improve the QoE for metaverse users. In so doing, some resource-intensive operations in the metaverse applications, such as avatar physics emulation and graphics rendering computation, can be accomplished at the edge. The classification of these edge devices into the edge layer can greatly enhance the variability and flexibility of metaverse services that have diverse performances and specific requirements.

2) Cloud Layer: The cloud layer integrates and encapsulates various high-performance resources in distant data centers and delivers them on demand via virtualization technologies. Currently, various AI models, requiring masses of computing resources, can be trained in the cloud. The trained models can be pushed to the network edge for inference and predictions, which is unquestionably beneficial for metaverse applications. Furthermore, various metaverse infrastructures and platforms, such as Google Stadia[1] and GoldenKnights: Metaverse[2], can be deployed in the cloud.

3) Metaverse Layer: The bottom layer of this architecture is composed of a broad range of IoT devices deployed by MSPs or metaverse platforms that host these MSPs. These IoT devices serve a crucial role in environmental sensing, data collection and integration, and the generation of AR/VR tasks. For instance, the data acquired through these devices can be utilized for real-time data synchronization between the physical world and the digital counterparts in the metaverse.

[1]https://stadia.google.com
[2]https://www.goldenknights.io/en

IV. Why and How: Edge Computing for Metaverse

Focusing solely on latency reduction is insufficient when considering the impact of edge computing on the metaverse. Edge computing has the potential to reshape the current cloud-based physical infrastructure of the metaverse. That is to say, certain metaverse platforms can be deployed at the network edge, to cater to the stringent latency requirements of various metaverse applications and services. In addition, as one of the enabling technologies for the metaverse, edge computing is also interwoven with other technologies such as digital twins and blockchain.

In the next, we strive to address the interrogation of why and how edge computing can boost the development of an ultra-real metaverse from different perspectives and aspects.

A. Edge Computing: Indispensable Building Block for Metaverse.

We present several advantages of edge computing, so as to answer why edge computing is one of the indispensable building blocks for the metaverse.

1) Latency Reduction: The greatest merit of edge computing, as mentioned earlier, is to reduce the response latency for various metaverse applications and tasks, by moving computing, storage, caching, and networking resources in close proximity to the users. According to the performance characteristics of edge devices, computations, such as the avatar physics emulation and graphics rendering computation in immersive VR/AR tasks, can be selectively offloaded to suitable edge devices for execution. For large and divisible metaverse tasks, the computations can be properly spread over between the edge device and the cloud center. For instance, the resource-intensive part can be accomplished at the edge, while other parts that consume plenty of storage resources can be accomplished in the cloud center.

2) Edge-Aided Digital Twins: An increasing upsurge in the number of edge devices makes computing resources virtually ubiquitous. Edge computing enables computations to be accomplished in close proximity to data sources. Furthermore, edge computing can efficiently assist in digital twins during real-time data synchronization between the digital counterparts in the metaverse and the physical world. For instance, deploying edge devices at places MSPs are interested can efficiently process the data gathered and used for synchronous updates, such as data preprocessing, caching, and computation undertaking.

Likewise, digital twins can also improve the efficiency of edge computing systems. For instance, deploying digital twins at the edge can model the edge devices in the virtual space, knowing their state information including historical behaviors, computing, caching, and networking capabilities. In so doing, digital twins can help edge computing systems efficiently filter streaming edge data or decide on suitable edge devices for task offloading.

3) Edge Intelligence: The combination of AI and edge computing results in an interdisciplinary, termed *edge intelligence* [13]. Edge intelligence overcomes a major shortcoming of cloud-based AI model training and inference, that is, the long latency incurred by raw data transmission via the backbone (core) networks. For instance, compared to general AI approaches that consist of cloud-based model training and edge-based inference, federated learning (FL) has demonstrated more astonishing capabilities in addressing issues of long latency and privacy in edge-cloud environments.

Moreover, edge intelligence brings enormous benefits such as real-time data analysis and decision-making, low-cost communication overhead, and energy consumption saving. All these merits surely boost the immersive metaverse experience.

4) Bandwidth Usage Reduction: Edge computing moves computation, caching, and storage to the logical network edge, thus relieving the tremendous burden of backhaul networks. Edge intelligence further reduces bandwidth usage by leveraging various AI technologies. Particularly, raw data can be processed at the edge, without the need to offload to the cloud unless necessary. Accordingly, edge computing offers the opportunity for various metaverse applications with high-bandwidth demands to be deployed at the edge.

5) Security and Privacy Protection: The risk of user data leakage always exists in cloud computing, and preventing privacy exposure has been a hot topic in recent years [14]. Compared to cloud computing, edge computing mitigates the risk of privacy exposure to a great extent. For instance, data can be stored hierarchically in edge-cloud cooperation, that is, sensitive and private data can be stored and processed at local edge devices while insignificant data can be processed in the cloud. In the meanwhile, attention has been increasingly paid to some accompanying security and privacy issues in edge computing, such as the identification of unreliable and malicious edge devices.

For all intents and purposes, edge computing is destined to be an indispensable building block for the metaverse.

B. How to Boost Development of Metaverse

While edge computing is crucial to the metaverse, the specifics of how edge computing can be utilized and which case studies can drive the growth of the metaverse remain an open issue. In what follows, we will explore these questions from different perspectives.

1) Data Preprocessing: The metaverse necessitates the real-time synchronization of data between the virtual and physical worlds. A large number of IoT devices deployed by MSPs generate massive amounts of data for virtual-reality data synchronization. Edge computing can play a vital role in this process. By deploying edge devices at appropriate locations to preprocess collected data, the efficiency and effectiveness of data synchronization can be further enhanced.

The deployment of edge devices in this process can be formulated as an optimization problem. For instance, reliable wireless communication links should be established before data transmission between the edge and IoT devices. In this context, where and which edge devices (Mini-edge, Micro-edge, or Macro-edge) should be placed to realize full wireless coverage is thus an optimization problem. The objective is to minimize the costs in terms of energy consumption or the number of edge devices utilized, with a focus on green energy-saving and sustainability.

2) Business Integration: Underlying metaverse infrastructure can host multiple MSPs, and these MSPs may require various forms of business cooperation such as cross-platform VR/AR games development, and virtual service compositions to fulfill more complicated functionality. In this context, some lightweight business integrations can be carried out at the edge. By utilizing the performance characteristics of edge devices, conducting business integrations at appropriate edge devices can lower operational costs, alleviate backhaul pressure, increase processing speed, and enhance QoE.

The business integration exemplified by service composition can be modeled as a combinatorial optimization problem. For instance, multiple MSPs may host function-similar (identical) metaverse services. A complicated metaverse service can be established by composing functionally different services. Since every single service can be provided by multiple MSPs, this composition can be regarded as a combinatorial optimization problem, which seeks the optimal combination for metaverse services. In this process, the evaluation metrics include the minimization of costs for MSPs or the maximization of QoE for metaverse users.

3) Computation Undertaking: Edge computing enables computation tasks to be performed at the edge instead of being offloaded to the cloud, which brings tremendous benefits for time-sensitive tasks in the metaverse. As a matter of fact, computation tasks are ubiquitous in the metaverse, such as graphics rendering and computations on momentum and mass pertaining to avatars' activities. Scheduling these tasks into suitable edge devices, based on their performance requirements, can guarantee ultra-low latency for metaverse users.

The computation undertaking at the edge requires not only the allocation of computing resources, but also the cooperation among edge devices, as well as between edge devices and the cloud center, taking into account the relatively limited capabilities of edge computing in comparison to cloud computing. Actually, the allocation of computing resources at the edge can be regarded as an optimization problem, which aims to minimize the response latency for metaverse users, and energy consumption and spectrum resources for MSPs, or maximize the gain described as a hybrid function that balances the trade-off between response latency, energy consumption, and spectrum resources.

4) Energy Supply: Considering the energy-hungry feature of massive IoT devices used for data sensing and information gathering in the metaverse, edge computing can play a significant role in promoting sustainable development through the combination of EH and WPT. Edge servers, such as RSU and BS, can harvest green energy including solar, wind, and luminous energies to achieve a self-sustainable energy supply,

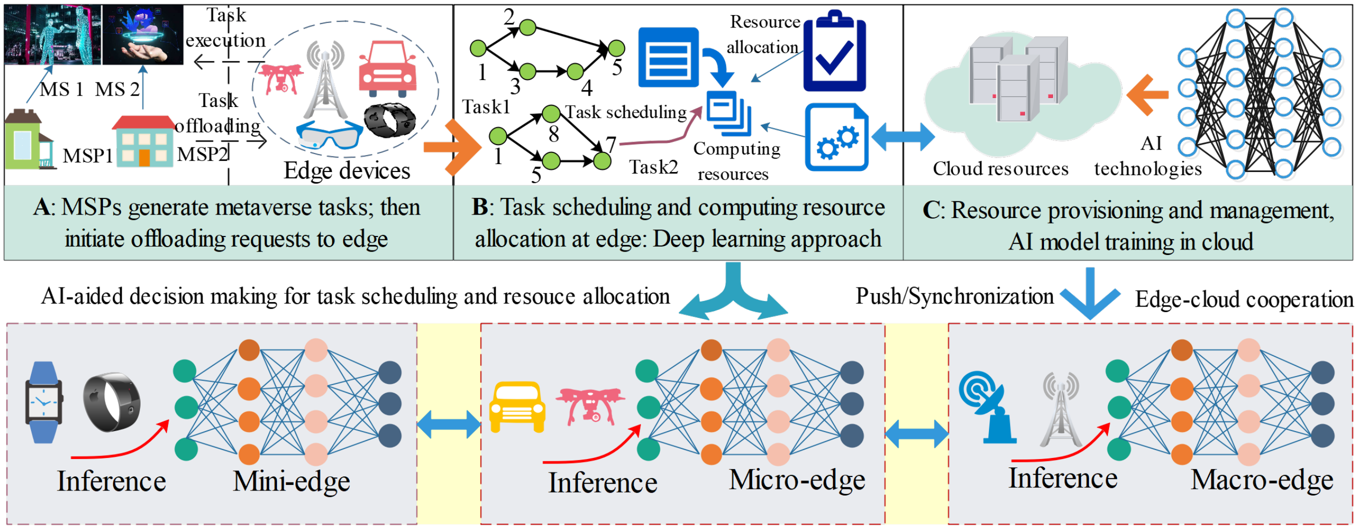


Fig. 3: A use case to illustrate how edge computing boosts the metaverse in terms of task offloading and resource allocation, and edge intelligence is adopted to aid decision-making, which consists of cloud-based AI model training and edge-based inference.

and further broadcast harvested energy wirelessly to charge IoT devices, using dedicated energy transmitters [15].

This process typically involves green energy scheduling, that is, how to distribute green energy among IoT devices to cater to the variety and energy consumption pattern, from the perspective of IoT devices, and how to distribute green energy among various metaverse tasks to minimize the response latency for metaverse users, or maximize the profits from the perspective of MSPs.

V. Use Case Study

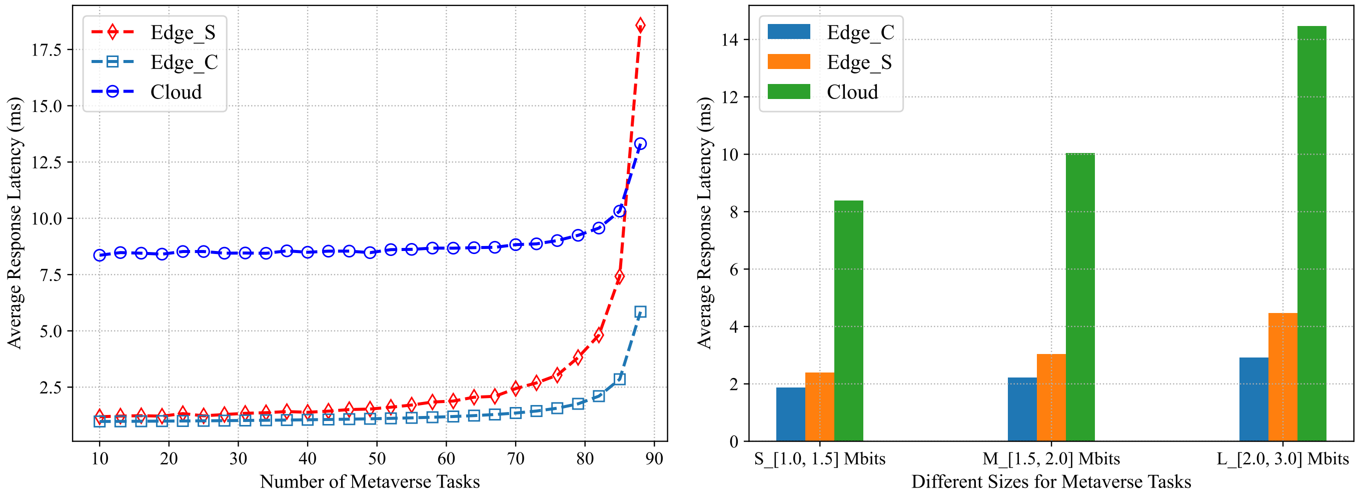
In order to exemplify the potential of edge computing in boosting the progress of the metaverse, a use case is presented, emphasizing the collaborative synergy between edge computing and cloud computing in terms of task offloading and resource allocation. This intricate process is visually represented in Fig. 3, wherein edge intelligence plays a pivotal role in decision-making processes related to the selection of edge devices and task offloading. The specific details of this cooperative framework are outlined as follows:

- Two MSPs are depicted in this figure, each offering distinct Metaverse Services (MS). Both services entail the generation of computationally intensive tasks with stringent latency requirements. Notably, the execution of these tasks is delegated to edge devices rather than centralized cloud centers.
- Task performing at the edge is complicated in the sense that it involves task partition, task scheduling, edge device selection and computing resource allocation. For instance, task 1 can be modeled as a directed acyclic graph (DAG) that is divisible and has five subtasks. Scheduling the five subtasks into edge devices for execution needs to consider the features of tasks and edge devices such as computing needs and requirements, and the corresponding optimization problem is often NP-hard.
- In this case, a deep learning-based approach is adopted to tackle the task scheduling problem. For instance, deep reinforcement learning (DRL) is applied to various optimization problems, ranging from resource allocation to task offloading. In particular, an agent learns experience from the interaction with surrounding environments, and then adopts the “best” action to explore the environment and obtain a reward.
- Considering the insufficient capabilities of edge devices, especially Mini-edge, for AI model training, edge-cloud cooperation is applied in this case, for fully exploiting the computing power of the cloud center. For instance, an agent can be deployed in the cloud, which is responsible for interacting with the environment such as action design, and action dissemination among MSPs, and edge devices. The actions consist of both discrete and continuous variables. The discrete ones can represent which edge devices are selected, while the continuous ones represent how computing resources are allocated among the metaverse tasks.

VI. Performance Evaluation

In this study, we aim to investigate the potential of edge computing in boosting the user experience within the metaverse through extensive simulations. Our experimental setup involves an edge computing-enabled metaverse system, comprising deadline-specified computation tasks generated by metaverse applications. The system incorporates edge devices from the three aforementioned categories, as well as a cloud center that offers abundant computing resources. The number of edge devices and metaverse tasks is randomly determined within the ranges of [5, 10] and [10, 90], respectively. Additionally, the task size is randomly assigned within the range of [1, 3] Mbits. The execution of these tasks can be performed by either the cloud center or the edge devices.

In the case of task execution at edge devices, two distinct approaches are employed to determine the offloading destination and allocate computing resources. The first approach, referred



(a) Latency with different number of tasks

(b) Latency with different task sizes

Fig. 4: Evaluation on average response latency for different approaches

to as "Edge_S", adopts a random selection process for the offloading destination and subsequently assigns the available computing resources of the edge device to the task. The second approach, known as "Edge_C", takes a performance-oriented standpoint and seeks to optimize the average response latency across all metaverse tasks within the edge computing system. Furthermore, the "Cloud" approach indicates that metaverse tasks are offloaded and executed at the cloud center.

The simulation results are presented in Fig. 4, where Fig. 4a provides a comparative analysis of the average response latency for the three approaches with an increasing number of metaverse tasks, while Fig. 4b presents a similar comparison for various task sizes. The findings clearly indicate that exhibits a substantial acceleration in the execution of metaverse tasks when contrasted with cloud computing. Furthermore, it is evident that the "Edge_C" approach outperforms the "Edge_S" approach due to its consideration of crucial factors influencing task computation, including network bandwidth, computing capabilities, idle resources of edge devices, and task requirements. It is worth noting that the performance of edge computing is inherently constrained by the computational power of the edge devices. As illustrated in the figure, the "Edge_S" approach experiences a rapid escalation in average response latency with an increasing number of offloaded tasks or an augmentation in the sizes of individual tasks. This observation arises from the random selection for offloading destination and computing resources allocation in the "Edge_S" approach, leading to workload imbalances among edge devices, ultimately resulting in heightened average response latency.

VII. Challenges and Potential Solutions

Edge computing plays a pivotal role in the establishment of the metaverse, however, there are still significant challenges that require to be solved urgently. Herein, we offer some insights into these challenges and provide guidance for potential future directions in the field of edge computing and its role in the metaverse.

A. Security and Privacy Issues

Edge computing for the metaverse presents a promising solution to overcome the drawbacks of cloud-based metaverse systems, specifically with regard to data leakage and privacy exposure due to long data transmission and centralized data management. Despite these advantages, security and privacy issues remain a significant challenge, particularly in the presence of malicious edge devices in the system. The potential presence of malicious edge devices, particularly those from Mini-edge, can pose a significant risk to privacy and security within the metaverse. In the event of malicious behavior, the presence of these devices can lead to adverse consequences. In the best-case scenario, such devices can potentially result in the disclosure of sensitive information during task execution. However, in the worst-case scenario, they have the potential to manipulate execution results, which can severely undermine the trust of metaverse users.

Given these security and privacy risks, it is imperative to develop and implement more effective strategies that address both the identification of unreliable and malicious edge devices, as well as the secure processing and analysis of data within the metaverse. These measures are crucial to ensuring the integrity of the metaverse ecosystem and maintaining the trust of its users.

B. Portability and Quantity Requirement

Before the metaverse can gain widespread adoption in daily life, it must address the issues of scalability and accessibility. On one hand, the initial metaverse platforms have limited capabilities, allowing only for a limited number of participants. It is challenging to scale up to more participants, owing to limited computing power and bandwidth requirement. On the other hand, the requirement of wearable devices (e.g., headsets) to fully experience virtual spaces can be seen as a barrier to widespread adoption.

These factors give rise to novel requirements for edge computing, particularly concerning: i) The need to seamlessly integrate a larger multitude of edge devices or IoT resources, even going beyond regular provisioning, in order to ensure that ubiquitous computing power can effectively support and cater to the expansive demands of the metaverse. ii) The imperative to devise lightweight and portable devices that encompass both edge computing capabilities and a diverse array of immersive technologies. This endeavor aims to empower individuals, irrespective of their location or temporal constraints, with unrestricted access to the metaverse at any given moment.

C. Testbed Construction

Several prominent high-tech enterprises, including Meta (formerly known as Facebook), have announced the development of their own metaverse platforms, which provide an opportunity to validate and examine a multitude of algorithms and strategies. However, within the academic realm, substantial endeavors remain to be undertaken in this domain. Executing diverse algorithms associated with the edge computing-enabled metaverse demands the deployment of distributed computing infrastructures that traverse disparate entities, a resource-intensive and restrictive endeavor in practical settings. As an alternative approach, devising a testbed that facilitates a more flexible and cost-effective validation of proposed algorithms and strategies emerges as a more viable option.

VIII. Conclusion

The concept of the Metaverse has garnered significant attention in recent years. Prior research has predominantly focused on exploring crucial enabling technologies for its establishment, including digital twins, blockchain, and edge computing, among others. However, it is far from being adequate in our view, since the specific manner in which edge computing stimulates the development of the metaverse remains an unresolved issue. In this article, we strive to give an architectural overview of the edge computing-enabled metaverse. We elucidate the advantages of integrating edge computing into the Metaverse and present a compelling use case to illustrate its significance. Furthermore, we discuss various challenges associated with this integration, aiming to inspire further research interest in this emerging domain.

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Chaogang Tang [M] (cgtang@cumt.edu.cn) received his B.S. degree from the Nanjing University of Aeronautics and Astronautics, Nanjing, China in 2007, and Ph.D. degree from the School of Information Science and Technology, University of Science and Technology of China, Hefei, China, and the Department of Computer Science, City University of Hong Kong, under a joint Ph.D. Program, in 2012. He is now an assistant professor with the School of Computer Science and Technology, China University of Mining and Technology. His research interests include vehicular vehicular edge computing, fog computing, and internet of things.

Huaming Wu [SM] (whming@tju.edu.cn) received the B.E. and M.S. degrees from Harbin Institute of Technology, China in 2009 and 2011, respectively, both in electrical engineering. He received the Ph.D. degree with the highest honor in computer science at Freie Universität Berlin, Germany in 2015. He is currently an associate professor at the Center for Applied Mathematics, Tianjin University. His research interests include wireless networks, mobile edge computing, Internet of Things and complex networks.

Ruidong Li [SM] (liruidong@ieee.org) received his bachelor's degree in engineering from Zhejiang University, China, in 2001, and received his Ph.D degree from the University of Tsukuba in 2008. Currently, he is an associate professor in College of Science and Engineering, Kanazawa University, Japan. His research interests include big data networking, information-centric network, network security, and quantum Internet.

Chunsheng Zhu [M] (chunsheng.tom.zhu@gmail.com) received the Ph.D. degree in electrical and computer engineering from The University of British Columbia, Vancouver, Canada, in 2016. He is currently an associate professor with the College of Big Data and Internet, Shenzhen Technology University, Shenzhen, China. His research interests include Internet of Things, wireless sensor networks, cloud computing, big data, social networks, and security.

Joel J. P. C. Rodrigues [S'01, M'06, SM'06, F'20] (joeljr@ieee.org) is a professor with COPELABS, Lusófona University, Campo Grande 376, 1749-024 Lisbon, Portugal. He has served as the Director for Conference Development (IEEE ComSoc Board of Governors) and Chair of the IEEE ComSoc eHealth and Communications Software TCs. He has authored or coauthored over 1000 publications, three books, two patents, and one ITU-T Recommendation.