Slicing4Meta: An Intelligent Integration Framework with Multi-dimensional Network Resources for Metaverse-as-a-Service in Web 3.0

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Abstract—As the next-generation Internet paradigm, Web 3.0 encapsulates the expectations of user-centric immersion and interaction experiences in a decentralized manner. Metaverse, a virtual world interacting with the physical world, is becoming one of the most potential technology to push forward with Web 3.0. In the Metaverse, users expect to tailor immersive and interactive experiences by customizing real-time Metaverse services (e.g., augmented/virtual reality and digital twin) in the three-dimensional virtual world. Nevertheless, there are still no unified solutions for the Metaverse services in terms of orchestration and management. It is calling for a continuous and seamless evolution of mobile systems to support Metaverse services, and thus bring Metaverse into reality. In this paper, to provide scalable subscription solutions for Metaverse services, we propose a new concept, named Metaverse-as-a-Service (MaaS), in which various physical-virtual components and technologies in the Metaverse can be delivered as services. Furthermore, to unify the orchestration and management of MaaS, we propose a novel framework, called Slicing4Meta, to customize Metaverse services by intelligently integrating MaaS models and the associated multi-dimensional resources on the components and technologies. Additionally, we propose the classification for typical Metaverse services based on the quality of experience (QoE) requirements and illustrate how to fulfill the QoE requirements under the Slicing4Meta framework. We then illustrate a virtual travel study case, in which we examine the relationship between the QoE and the multi-dimensional resources by quantitatively modeling the QoE of Metaverse users. Finally, we discuss some open challenges of Slicing4Meta and propose potential solutions to address the challenges.

I. INTRODUCTION

Web 3.0 is defined as the next generation World Wide Web, which revolves around “decentralization” and “user-centric”. It is anticipated that Web 3.0 will be delivered with decentralized services that require user-centric immersive and interactive experiences. By promising to support these immersive services (e.g., augmented reality (AR)/virtual reality (VR), healthcare and education), Metaverse is becoming one of the most potential technologies to envision Web 3.0. However, only few Metaverse services can be well supported by the current mobile systems. On the one hand, the quality of experience (QoE) requirements of Metaverse services, such as ultra-low interaction time for massive physical-virtual world synchronization in the digital twin, may go beyond the capability of current mobile systems. On the other hand, there are no unified solutions for the current mobile systems to flexibly orchestrate and manage Metaverse services. It is thus calling for a continuous and seamless evolution of mobile systems to facilitate the development of Metaverse services.

The mobile systems for supporting Metaverse services have yet to be developed. However, it is foreseeable that the eventual mobile system will be a convergence of a service-oriented perspective and an evolutionary perspective. Specifically, the service-oriented perspective focuses on meeting diverse QoE requirements of Metaverse services over a common network infrastructure [1], [2]. This requires on-demand subscription solutions for tailoring and isolating the specific services, as the services should independently operate without any influence [1], [2]. The evolutionary perspective is adopted to scale up and improve network capabilities significantly (e.g., scalability and efficiency), which requires a more flexible and scalable framework to orchestrate and manage Metaverse services.

On the one hand, “as-a-service” can provide an effective and flexible subscription solution for tailoring and isolating specific Metaverse services in an on-demand basis. Recently, both academia and industry have begun designing everything-as-a-service (XaaS) to deliver scalable computing resources. XaaS means that everything over cloud systems can be regarded as a service [3]. Intuitively, Metaverse can benefit from “as-a-service” models. In Metaverse, everything such as essential components (e.g., infrastructure and platform) and technologies (e.g., blockchain and artificial intelligence), can be delivered as service models (Part I in Fig. 1), i.e., Metaverse-as-a-Service (MaaS). By building a Metaverse service instance (MSI) that consists of MaaS models, service providers can timely customize Metaverse services for users while guaranteeing the QoE requirements.

On the other hand, some prior studies have suggested that mobile systems should be constantly upgraded by integrating multi-dimensional heterogeneous resources such as communication resources, computing resources, storage resources, and even various radio access technologies (RATs) to scale up and improve network capabilities [4]–[6]. By integrating MaaS models and multi-dimensional heterogeneous resources, new MSIs can be flexibly constructed in mobile systems by modifying existing MaaS models or creating new MaaS models, and thus achieving cost-efficient and performance-optimal orchestration and management of mobile systems.

However, it is rather complicated for mobile systems to integrate various MaaS models and the associated heterogeneous resources for diverse Metaverse services. This is due...
to the highly dynamic and complex nature of the Metaverse environments and the computation complexity incurred by the MaaS integration. Fortunately, the rapid development of artificial intelligence (AI) paves the way for applying AI in the Metaverse to solve such problems [4], [5], [7], [8]. Specifically, the AI-assisted framework can cope with the dynamic orchestration and management of MaaS models by predicting and updating physical-virtual world status [7], [8]. Additionally, based on AI technologies/algorithms, Metaverse users can continuously interact with the physical-virtual worlds and thus obtain optimal subscription solutions in such complex environments by using trial and error learning processes [9].

In this paper, we propose an evolved mobile system framework for providing customized Metaverse services, named Slicing4Meta, by introducing intelligent integration of MaaS models and multi-dimensional resources. The main contributions of this paper are summarized as follows:

(1) To tailor subscription solutions for Metaverse services while fulfilling diverse QoE requirements requested by these services, we propose a new concept, namely Metaverse-as-a-Service (MaaS), where various components and technologies in Metaverse can be delivered as services.

(2) To unify the orchestration and management of MaaS, we propose a novel intelligent resource integration framework, called Slicing4Meta. Different from the conventional types of network services, we define two typical types of Metaverse services, including VR/AR immersive services and digital twin services to facilitate the holistic construction of Metaverse service instances.

(3) We illustrate a virtual travel case, where we quantitatively examine the relationship between the QoE of users and multi-dimensional resources under the Slicing4Meta framework. Additionally, some open challenges including isolation and security under Slicing4Meta and the potential solutions are presented.

II. Slicing4Meta for Metaverse Services

In this section, we first give the definition of MaaS. Then we propose an evolved network framework for mobile systems, called Slicing4Meta, to support Metaverse services by customizing various MaaS models and the corresponding multi-dimensional network resources. Finally, we present the details for the instantiation of Metaverse services.

A. Metaverse-as-a-service (MaaS)

MaaS is defined as an on-demand subscription solution that allows businesses and/or operators to develop and enforce various forms (e.g., presence, management, orchestration and implementation) in Metaverse to support Metaverse service processing, collaboration, business operation, products and other related scenarios. Similar to the XaaS in cloud systems, everything in Metaverse can be regarded as a delivery model, which can be easily created and/or modified as function modules.

As shown in Fig. 1 (Part I), MaaS mainly consists of component-as-a-service (CaaS) and technology-as-a-service (TaaS). The CaaS mainly refers to the as-a-service models that supply multi-dimensional resources such as software-as-a-service (SaaS). SaaS refers to a software delivery model where software providers host the applications and make them accessible over the Internet. The TaaS mainly refers to the as-a-service models that consume multi-dimensional resources such as network slice-as-a-service (NSaaS). NSaaS refers to the delivery model in terms of functionalities, topology, policies, and parameters that are mapped from Metaverse service demands.

A MaaS model could be a single delivery model or a composite delivery model that consists of multiple individual delivery models. By packaging, modifying, delivering and integrating MaaS models, businesses and/or operators can quickly provide customized solutions to support Metaverse services. Indeed, all these MaaS models are built upon various multi-dimensional network resources (Part II in Fig. 1) in the form of supplying and/or consuming certain resources. Indeed, there are a large number of alternative ways to form the required MaaS models, which increases the difficulty in instantiating Metaverse services especially when the number of services or the types of the required resources is large. Therefore, a resource integration framework is needed to configure optimal MaaS models for specific services while guaranteeing QoE requirements.

B. Slicing4Meta Framework

Researchers from both academia and industry have widely agreed that Metaverse should be enabled by the software-defined network (SDN) and virtualization technologies. As per this agreement, we propose an evolved framework, namely Slicing4Meta, as shown in Fig. 2.

Slicing4Meta consists of five layers, including the physical world layer (PWL), technology layer (TL), MaaS and resource integration layer (MRIL), Metaverse service instance (MSI) layer, and AI layer. Different from 5G network slice architecture, two more layers including TL and MRIL to facilitate the customization of Metaverse services are specified in Slicing4Meta. Specifically, the TL represents the technologies needed to connect the physical world and virtual world such as human-computer interaction and holography communications.
The MRIL includes MaaS model layer and a virtual multi-dimensional resource pool built upon Metaverse, which is used to configure the optimal MaaS models with certain resources for specific Metaverse services while guaranteeing QoE requirements. In addition, PWL consists of real objects in the physical world such as physical network resources, physical entities, and AR/VR devices. The AI layer consists of local AI controllers and a global AI controller, where AI technologies are integrated into SDN controllers to intelligently orchestrate and manage various MaaS models while enhancing system performance, flexibility and scalability. In the MSI layer, an MSI represents an instance of Metaverse service, which consists of MaaS models and multi-dimensional resources for running these MaaS models.

C. Instantiation of Metaverse Service

A Metaverse service can be tailored via the instantiation of MSI in terms of the required MaaS models, virtual resources, virtualized entities and the corresponding physical entities. Depending on the QoE requirements, a service can be instantiated as an existing MSI or a new MSI. For example, as shown in Fig. 3, both the AR and VR service can be instantiated as MSI 1 which contains dedicated and/or shared MaaS models and the corresponding resources. In the context of current 5G networks, the MSIs are similar to the customized network slice instance [10]. The main differences between them are the heterogeneous resources integration, the associated technologies and the supported scenarios. Inspired by network slice instance-related management functions in 3GPP TR 28.801 [10], we propose the following three instantiation-related management functions to manage MSIs and thus support Metaverse services.

1) Metaverse Service Management Function (MSMF): As shown in Fig. 3, MSMF is responsible for translating the requirements of users in the physical world to the requirements of Metaverse services in the virtual world via some advanced technologies (e.g., human-computer interaction) and/or devices (e.g., AR/VR glasses). Moreover, it is responsible for managing Metaverse services provided by virtual service providers, where MSMF should be notified about any changes in terms of MSIs, MaaS models, network capability, multi-dimensional resources, and service requirements in physical-virtual worlds.

2) Virtual orchestration and management Function (VMOF): VMOF is responsible for managing and orchestrating MSIs, controlling the life-cycle of MSIs (preparation, planning, run-time and decommission) [10], and interacting with the domain-specific orchestration. Moreover, it can either reuse an existing MSI or create a new MSI from the perspective of the global Metaverse domain by monitoring the performance of MSIs.

3) MaaS Management Function (MMF): MMF is responsible for instantiating, configuring, managing and orchestrating MaaS models and the corresponding resources. Moreover, it analyzes the requests from VMOF and determines the MaaS models and multi-dimensional resources to be used/modified. As shown in Fig. 3, the instantiation process of MSIs consists of three steps, as follows:

- **Step I**: When users send the Metaverse service requests, the MSMF first translates/updates the Metaverse services related requirements (e.g., service type and QoE requirements) and then sends them to VMOF.
- **Step II**: Once VMOF receives the Metaverse services related requirements, it converts them to Metaverse service sub-instance related requirements (e.g., MaaS models, multi-dimensional resources and QoE requirements) and then sends the requirements to MMF.
- **Step III**: The MMF analyzes the requirements from VMOF. Moreover, MMF and VMOF communicate with each other to decide whether to modify existing MSIs and MaaS models and/or create new MSIs and MaaS models.

D. Intelligent MSIs Integration of Slicing4Meta

Orchestrating and managing MSIs require judicious and timely coordination of MSIs, especially when various conflicts simultaneously occur in creating, modifying, and scheduling MSI and MaaS models. Therefore, we employ two-tier AI-enabled SDN controllers (namely global AI controller and local
AI controller) in our Slicing4Meta framework. Specifically, the global AI controller located at a central cloud maintains a global view of Metaverse to integrate and manage Metaverse services and MSIs with different types. The local AI controller located at MSI clusters is to manage/orchestrate MSIs for specific types of services by creating/modifying MaaS models and the corresponding resources to users.

As shown in Fig. 3, AI controllers mainly play important roles in the phases of preparation (Step I), planning (Step II), and run-time (Step III) during the life-cycle of MSIs [11]. Specifically, in the preparation phase, the global AI controller predicts the service type and the QoE requirements of Metaverse users via using prediction technologies (e.g., data mining and neural networks). Specifically, the global AI controller first integrates and designs the necessary Metaverse environment (e.g., MSIs, MaaS models and multi-dimensional resources). Then, the global AI controller sends the design results to the associated local AI controller. In the planning phase that involves the real-time instantiation, configuration and activation of MSIs, the local AI controller creates and configures MSIs by dynamically creating, revising and adjusting dedicated/shared MaaS models and the corresponding resources via online AI tools. In the run-time phase, MSIs are capable of handling service flows to support Metaverse services of certain types, where the local AI controller is responsible for supervision (e.g., monitoring service flow, QoE and resource utilization) and modification (e.g., scaling MSI cluster and changing the capacity of MSIs). Meanwhile, the local AI controller timely reports the supervision and modification results to the global AI controller and obtains the feedback.

Through the Slicing4Meta framework, businesses/operators can intelligently create and manage MSIs intra-/inter- clusters at a relatively low cost. Meanwhile, the QoE requirements of users can be agilely guaranteed by intelligently integrating and scheduling various MaaS models, from which Metaverse is expected to become reality.

III. TWO TYPICAL TYPES OF METaverse SERVICES

In this section, we elaborate how to fulfill the requirements of the two major types of Metaverse services under the Slicing4Meta framework. As shown in Table I, the QoE requirements, involved heterogeneous resources, related MaaS models, and the corresponding Metaverse scenarios are listed.

A. Digital Twin Services

Many highly dynamic and complex scenarios such as Industry 4.0, manufacturing and smart city, require new service dimensions and experiences for different users and businesses/operators. Digital twin (DT), a virtual representation of a physical object, is a promising approach to cope with the afore-mentioned trends by running and simulating virtual replicas before physical objects are built and/or deployed. Naturally, DT services become an essential booster for facilitating DT development. Specifically, DT services can serve any phase of a physical object’s life-cycle such as design, creation, simulation, monitoring, building and running. Meanwhile, a large number of DT services, such as knowledge (part of data that may be extracted from existing data) services and algorithm services, are needed to build a functioning DT virtual world [12]. It is thus important to customize specific DT services by integrating and customizing various MaaS models to guarantee physical-virtual synchronization fidelity and service quality. As shown in Table I, necessary MaaS models for DT services are given from the following two aspects:

1. Component-as-a-service: Many components in DT systems, such as hardware (e.g., sensors and graphics processing units), software and infrastructures (e.g., virtual machines), can be regarded as service models to provide specific capabilities (e.g., computing, transmitting and analysis) by providing needed multi-dimensional resources. For example, sensor-as-a-service (e.g., Nexxiot’s sensors) provides specific communication protocols to support continuous data collection on physical objects.

2. Technology-as-a-service (TaaS): Some TaaS allows users to customize on-demand DT services by consuming multi-dimensional resources, where TaaS mainly performs the following functions: 1) Connecting the physical-virtual world as well as various DT systems, such as human-computer interaction technology-as-a-service and communication interface-as-a-service. 2) Managing massive data (collection, fusion, processing and analyzing), such as data transmission protocol-as-a-service, AI-as-a-service, decision tree-as-a-service and edge computing-as-a-service. In addition, some TaaS, such as time division, frequency division and wavelength division, can also be delivered as service models to provide the needed resources.
B. AR/VR Services

AR/VR services offer Metaverse users immersive experiences, where both the AR/VR devices and services should be popularized and functionalized to derive evolution to the immersive phases [13]. Many AR/VR devices in the PWL layer are licensed on a specific basis to deliver user-related features (e.g., user feelings and interaction signals), which require real-time interactive experiences such as ultra-low response time (below 1 ms) [4]–[6]. Moreover, in the MSI layer, specific AR/VR services pose stringent QoE requirements (e.g., below 1 ms) [4]–[6]. Therefore, to cope with these requirements in a unified manner, there is a significant need for integrating MaaS models and the associated multi-dimensional resources. By sharing and/or purchasing the integrated MaaS models in an on-demand and social interaction, require highly dynamic and complex technologies. Human-computer interaction, such as animation and rendering. Therefore, besides TaaS for DT services, technologies such as content creation technology (e.g., three-dimensional modeling and holography communication) and rendering processing technology (e.g., cloud rendering) can be delivered and/or integrated as service models [13].

IV. CASE STUDY FOR SLICING4META

To demonstrate the effectiveness of our Slicing4Meta framework, we present a virtual travel case study and corresponding simulation results in this section.

A. Metaverse Scenarios

We consider a basic virtual travel scenario on a beach, including two main Metaverse services (i.e., AR service and virtual-based service) [14]. Specifically, the AR service provides AR navigation services, AR maps, and extended reality experiences such as panoramic virtual mirror beach. Virtual-based services provide “beach experiences” by exploring a virtual world freely as avatars, which enables users to create and experience a virtual beach without limits in the virtual world and deliver the experiences back.

- Computation, storage and communication resources. Guaranteeing fluid synchronization between Metaverse users’ movements and visual perception is of importance for virtual travel. The synchronization includes complex procedures such as predicting user behavior and processing user interaction, which requires a large amount of computation, storage and network resources. For example, to support the real-time interaction of travel conditions, the computation frequency should be up to 300 GHz. Generally, IaaS and PaaS are expected to provide these required computing, storage and communication resources. These resources are first integrated into a virtual resource pool. Then, the global AI controller cooperates with local AI controllers to make decisions on deploying IaaS/PaaS models and the needed resources for virtual travel MSIs.

Data processing capabilities. (1) Data collection: The physical-virtual connection empowers the data collection process to update virtual representations (e.g., travel conditions and status) according to the physical reality. Specifically, from the physical world, data such as the visual and audio of users and the service requirements can be collected by AR/VR devices. From the virtual world, data such as weather and views can be monitored and simulated by virtual models. Therefore, device-as-a-service is needed to create/modify device patterns (e.g., access and state) to provide specific data collection capabilities and interaction protocols while monitoring-as-a-service is needed to monitor data and the corresponding functionalities. (2) Data fusion: The data collected from different sources (e.g., physical world, virtual world and service requirements) can be merged via data fusion algorithms to make the data more informative for travel monitoring. Therefore, data management-as-a-service is needed to provide centralized storage for various data sources. Additionally, AI algorithms such as neural networks and clustering algorithms can be used as services to facilitate data fusion and monitoring. Meanwhile, AI technologies such...
as computer vision and machine learning can be incorporated into controllers to realize intelligent data analysis, fusion and management.

Undoubtedly, during the construction process of the travel MSIs, some MaaS models supply multi-dimensional resources while others consume these resources. Therefore, before constructing specific MSIs via MaaS models, we should quantitatively analyze the QoE when integrating multi-dimensional resources of various MaaS models for a specific travel MSI. In this paper, similar to the idea of [15], we exploit a novel metric that consists of subjective experience (e.g., user feelings) and objective service quality (e.g., network performance and rendering capacity), named Meta-Immersion (MI), to model the QoE of Metaverse users.

| Subject Service Experience (I) | Feeling of Presence | Feeling of Interaction | Feeling of Pleasure |
|-------------------------------|---------------------|-----------------------|-------------------|
| Resolution                   |                      |                       |                   |
| Refresh Rate                  |                      |                       |                   |
| Response Time Operation delay |                      |                       |                   |
| Scenario Quality              |                      |                       |                   |
| Sensory Mismatch              |                      |                       |                   |

| Object Service Quality (II)  | Downlink Data Rate   | Uplink Bit Error Probability | Rendering Capacity |
|------------------------------|----------------------|-------------------------------|-------------------|
|                              |                      |                               |                   |

![Fig 4. A novel QoE metric in Metaverse: Meta-Immersion, and corresponding experience factors, service indicators and performance measures.](image)

As shown in Fig. 4, for the QoE of virtual travel services, the objective service quality is measured by the downlink rate, uplink bit error probability (BEP) and rendering capacity (Part II). Meanwhile, the subjective experience is affected by the feelings of travelers in terms of presence, interaction and pleasure, which can be reflected in the object service quality (Part I). For example, if a traveler is visiting a virtual beach, the traveler can feel the wind and sea waves, where the visual, auditory, and touch experiences of travelers can be affected by the rendering capacity. To derive the QoE in virtual travel, we establish the relationship between the objective service quality and the subjective experience (Part III). Specifically, in virtual travel, we use Weber–Fechner law to express the relationship between the stimulus of rendering experiences that travelers perceive from virtual travel and the perceived subjective feelings within the human sensory system. Formally, the difference perception is directly proportional to the relative change of the rendering stimulus [15]. Moreover, we use a normalization function to express the objective stimulus from the physical world. As shown in Part III, by combining the rendering and objective stimulus, we derive the expression of MI. When the rendering stimulus and/or objective stimulus change by more than a certain proportion of its actual magnitude, the AI controllers adjust the interaction and the objective service quality by integrating MaaS models in both virtual and physical worlds. In the following, we present the relationship between MI (the QoE of users), rendering capacity and downlink rate via the simulation result for virtual travel.

### B. Numerical Results

By evenly allocating rendering capacity to users, we examine the MI (i.e., QoE) under four different data rate conditions with respect to the number of users via simulation experiments. We consider the total rendering capacity of the rendering server is set to 4000 K, where 1 K resolution refers to 960 × 480 pixel resolution. Moreover, there are 56 virtual objects in the virtual travel scenario, where the number of virtual objects for a user is randomly chosen from \{1, 2, \ldots, 55, 56\} and the rendering capacity of each virtual object is set to 20K. The maximal data rate is set to 42 Mbit/s. Fig. 5 shows the MI (QoE) varying with the number of users under four different data rate conditions. As shown in Fig. 5, we find that when the total amount of rendering capacity is fixed (4000 K), Metaverse users with higher data rates always obtain better MI. In other words, when certain resources of MaaS models are insufficient, we can not only increase the resources by modifying the MaaS models but also can supplement the consumption from other MaaS models at the cost of other-dimensional resources.

![Fig 5. Meta-Immersion under four different data rate constraints.](image)

### V. Open Challenges and Solutions

Although the aforementioned good aspects of integrating MaaS models under the Slicing4Meta framework can be expected for supporting the potential Metaverse services in 6G, it also brings some challenges, such as isolation and security.

#### A. Isolation

As a Metaverse service instance (MSI) is customized for a specific service, an MSI should operate independently from other MSIs. Therefore, to guarantee the independent operation of all MSIs, isolation is a capital yet challenging requirement for supporting Metaverse services. Specifically, as various MSIs are built upon a common shared physical network, physical isolation (e.g., isolate entire physical resources) and logical isolation (e.g., split time and frequency) are always needed to avoid signal interference and resource conflicts in physical worlds. Moreover, as various MSIs may share the same MaaS models and virtual resources, scheduling isolation (e.g., resource scheduling, function scheduling and access mechanism) is important at the orchestration and management level, where both policy-based orchestration algorithms and mechanisms should be developed and integrated. Additionally,
a certain isolation degree for the type of Metaverse services is also needed, where the lower the isolation degree, the easier to share MSIs and MaaS models.

B. Security and Privacy

Under Slicing4Meta, security and privacy are always essential yet challenging issues. Specifically, as the Slicing4Meta framework is based on mobile wireless networks, an attack (e.g., single point of failure and distributed denial-of-service attacks) is a threat to both physical and virtual worlds. Moreover, as the massive amounts of data generated in the virtual and physical worlds involve lots of important and sensitive information, the confidentiality, integrity, and availability of data should be guaranteed. When the privacy data of user behavior is frequently transformed into digital assets, data management and protection should be enhanced.

Essentially, a few emerging technologies (e.g., blockchain and zero trust) can be configured into MSIs as a service under the Slicing4Meta. For example, blockchain can store submitted transactions to enable tracking and protection of digital assets [1], [2]. Moreover, it can store digital biometrics-based identities as well as physically authenticate identities. Furthermore, blockchain can be regarded as a complete economic service to connect the virtual world and real world, where users are allowed to trade virtual items in the same way as in the real world [2]. Zero trust eliminates the theft of sensitive information through continuous authentication and verification.

VI. CONCLUSION

In this paper, we have proposed MaaS to provide on-demand subscription solutions for customizing Metaverse services. To unify the orchestration and management of MaaS models, we have proposed a Slicing4Meta framework, in which two-tier AI controllers are used to facilitate the judicious and timely coordination of MSIs. Under the Slicing4Meta framework, we have specified two typical types of Metaverse services based on various QoE requirements and presented the specific MaaS models needed for each type of services. Moreover, we have illustrated a virtual travel case, where we quantitatively examine the relationship between the QoE of users and the multi-dimensional resources via simulation results. Finally, we have discussed the isolation and security/privacy issues of Slicing4Meta and proposed potential solutions to address these issues.

REFERENCES

[1] Y. Han, D. Niyato, C. Leung, D. I. Kim, K. Zhu, S. Feng, S. X. Shen, and C. Miao, “A Dynamic Hierarchical Framework for IoT-assisted Metaverse Synchronization,” arXiv:2203.03969, 2022.

[2] M. Xu, W. C. Ng, W. Y. B. Lim, J. Kang, Z. Xiong, D. Niyato, Q. Yang, X. S. Shen, and C. Miao, “A Full Dive into Realizing the Edge-enabled Metaverse: Visions, Enabling Technologies, and Challenges,” IEEE Communications Surveys & Tutorials, Early, Access, 2022.

[3] P. Banerjee, R. Friedrich, C. Bash, P. Goldsack, B. Huberman, J. Manley, C. Patel, P. Ranganathan, and A. Veitch, “Everything as a service: Powering the new information economy,” Computer, vol. 44, no. 3, pp. 36–43, 2011.

[4] W. Saad, M. Bennis, and M. Chen, “A Vision of 6G Wireless Systems: Applications, Trends, Technologies, and Open Research Problems,” IEEE Network, vol. 34, no. 3, pp. 134–142, 2020.

[5] F. Tariq, M. R. A. Khandaker, K. K. Wong, M. A. Imran, M. Bennis, and M. Debbah, “A Speculative Study on 6G,” IEEE Wireless Communications, vol. 27, no. 4, pp. 118–125, 2020.

[6] G. Wangqing, Z. Haijun, and L. V. C. M, “Customized Slicing for 6G: Enforcing Artificial Intelligence on Resource Management,” IEEE Network, vol. 35, no. 5, pp. 264–271, 2021.

[7] X. Shen, J. Gao, W. Wu, K. Lyu, M. Li, W. Zhuang, X. Li, and J. Rao, “AI-Assisted Network-Slicing Based Next-Generation Wireless Networks,” IEEE Open Journal of Vehicular Technology, vol. 1, pp. 45–66, 2020.

[8] W. Guan, H. Zhang, and V. C. Leung, “Customized Slicing for 6G: Enforcing Artificial Intelligence on Resource Management,” IEEE Network, vol. 35, no. 5, pp. 264–271, 2021.

[9] Y. J. Liu, G. Feng, Y. Sun, S. Qin, and Y. C. Liang, “Device Association for RAN Slicing Based on Hybrid Federated Deep Reinforcement Learning,” IEEE Transactions on Vehicular Technology, vol. 69, no. 12, pp. 15 731–15 745, 2020.

[10] 3GPP “TR 28.801 - V15.1.0 - 5G; Telecommunication Management; Study on Management and Orchestration of Network Slicing for Next Generation Network (3GPP TR 28.801 Version 15.1.0 Release 15),” Jan. 2018.

[11] W. Wu, C. Zhou, M. Li, H. Wu, H. Zhou, N. Zhang, X. S. Shen, and W. Zhuang, “AI-native Network Slicing for 6G Networks,” IEEE Wireless Communications, vol. 29, no. 1, pp. 96–103, 2022.

[12] Q. Qi, F. Tao, T. Hu, N. Anwer, A. Liu, Y. Wei, L. Wang, and A. Nee, “Enabling technologies and tools for digital twin,” Journal of Manufacturing Systems, vol. 58, pp. 3–21, 2021.

[13] C. Xi, “Virtual reality/augmented reality white papers,” 2017.

[14] T. Un, H. Kim, H. Kim, J. Lee, C. Koo, and N. Chung, “Travel Incheon as a Metaverse: Smart Tourism Cities Development Case in Korea,” in Proceedings of ENTER22 e-Tourism Conference, 2022, pp. 226–231.

[15] H. Du, D. Niyato, J. Kang, D. I. Kim, and C. Miao, “Optimal Targeted Advertising Strategy for Secure Wireless Edge Metaverse,” arXiv preprint arXiv:2111.00511, 2021.

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