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 management and orchestration. It is calling for a continuous evolution of scalable solutions and 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 management and orchestration 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 traveling 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 is defined as the Next generation of the World Wide Web, which revolves around "decentralization" and "user-centric". It is speculated that Web 3.0 will pop up with decentralized immersive applications that require user-centric immersion and interaction experiences. By supporting immersive and interactive experiences over a common network infrastructure, Metaverse is becoming one of the most potential technology to envision Web 3.0. In Metaverse, service providers (SPs) can provide tailored Metaverse services (*e.g.*, augmented reality (AR)/virtual reality (VR), healthcare and education) for users to meet their needs at will [1], [2]. However, only few Metaverse scenarios 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 digital twin, may go beyond the capability of current mobile systems. On the other hand, there are no unified on-demand subscription solutions (*e.g.*, customizing resources and technologies) for the management and orchestration of Metaverse services. It is thus calling for a continuous evolution of mobile systems to provide elastic and scalable solutions for enhancing the management and orchestration of Metaverse services while guaranteeing the rigorous QoE requirements.

Recently, the information and communication technology industry has begun to design everything-as-a-service (XaaS) to deliver scalable computing resources in an on-demand basis. XaaS means that everything over the networks can be regarded as a service [3]. Intuitively, Metaverse can benefit from "as-a-service" models, where the essential components and technologies in the Metaverse, such as platforms, infrastructures, software and artificial intelligence (AI), could be delivered as service models (Part I in Figure 1), *i.e.*, Metaverse-as-a-service (MaaS). These MaaS models are easily accessible, shared and/or reused, which allows SPs to timely provide new solutions to guarantee the QoE requirements of Metaverse services. Instead of paying for the conventional up-front expenditure for software and hardware, businesses and/or operators can integrate and purchase the MaaS models on-demand. By integrating and purchasing needed MaaS models, the businesses and/or operators can reduce the capital expenditure (CAPEX) and operating expense (OPEX) while simplifying the interactions of users. However, there still exist challenges in integrating, managing and orchestrating MaaS models among various physical-virtual components and functions to provide on-demand subscription solutions.

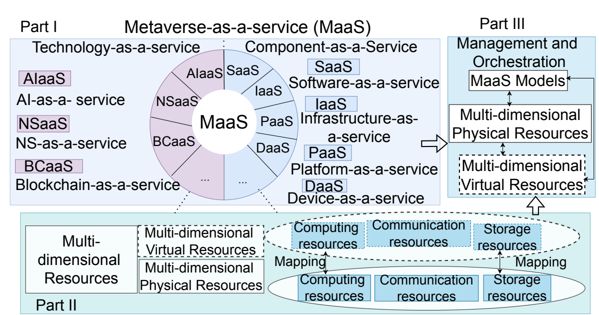

Fig. 1. Mataverse-as-a-service.

Some prior studies have suggested that mobile systems should be constantly upgraded by integrating multi-dimensional heterogeneous resources from various MaaS models to support customized immersive and interactive Metaverse services [4]–[6]. On the one hand, upgrading mobile systems profits from Metaverse, as mobile systems can achieve cost-efficient and performance-optimal management and orchestration by integrating multi-dimensional network resources such as communication resources, computing resources, storage resources, space resources, and even various radio access technologies (RATs) (Part II in Fig. 1). On the other hand, Metaverse profits from mobile systems, as mobile systems are expected to support tailored Metaverse services while guaranteeing the QoE requirements of Metaverse users.

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 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 management and orchestration 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 management and orchestration of MaaS, we propose a novel intelligent resource integration framework, called Slicing4Meta, which introduces two-tier AI controllers to facilitate integrating MaaS models and the associated multi-dimensional resources. Different from the conventional types of network services, we define two typical types of Metaverse services, including VR/AR services (*e.g.*, game and virtual traveling) and digital twin services (*e.g.*, smart home and manufacturing), to facilitate the holistic construction of Metaverse service instances.

(3) We illustrate a virtual traveling case, in which 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 to address the challenges are presented.

II. Slicing4Meta for supporting 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 includes software-as-a-service (SaaS), infrastructure-as-a-service (IaaS), platform-as-a-service (PaaS), hardware-as-a-service (DaaS), etc. Specifically, SaaS refers to a software delivery model where software providers host the applications and make them accessible over the Internet. PaaS refers to a tool and/or physical-virtual environment to develop, manage and run the applications. IaaS is a network infrastructure resource delivery model that provides network resources with scalability, such as servers and base stations. Moreover, the TaaS includes AI-as-a-service (AIaaS), network slice-as-a-service (NSaaS), etc. Specifically, AIaaS refers to off-the-shelf AI tools that enable businesses/operators to implement, use, and/or scale AI technologies and algorithms, such as deep learning for data analysis. 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 covers 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 providing and/or consuming the resources. For example, IaaS may provide computing and storage resources while AIaaS may consume communication and computing resources. In other words, various MaaS providers may offer limited support in integrating, designing and managing their MaaS models and the corresponding resources. Therefore, an integration framework is imperative yet urgent to support the customized Metaverse services.

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.

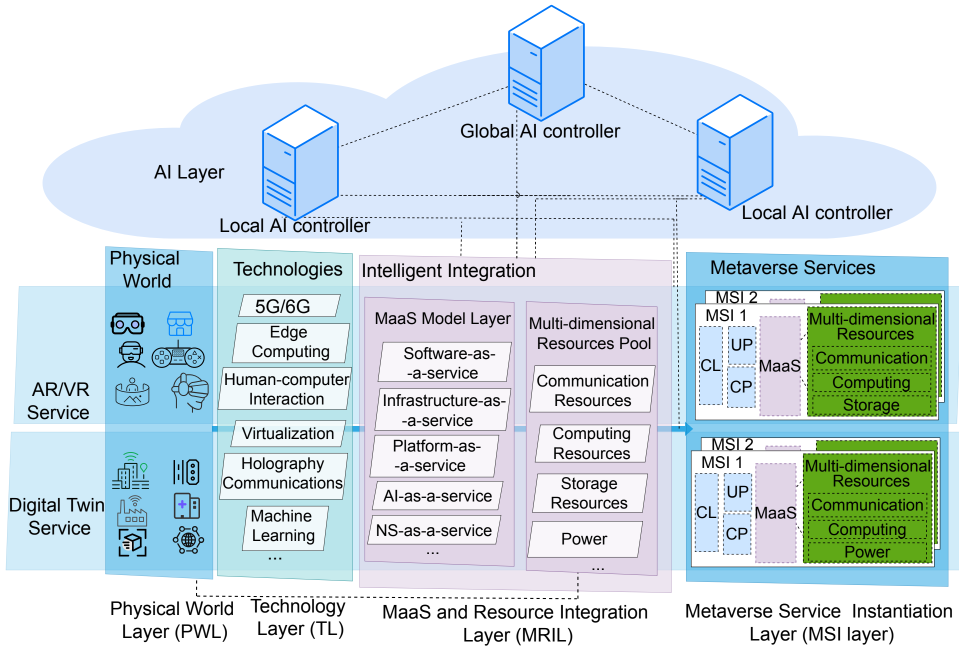

Fig. 2. Slicing4Meta architecture for Metaverse

Slicing4Meta consists of five layers, including physical world layer (PWL), technology layer (TL), MaaS and resource integration layer (MRIL), Metaverse service instance (MSI) layer, and AI layer. Specifically, PWL consists of real objects in the physical world such as physical network resources, physical entities, and AR/VR devices. TL represents the technologies that are needed to connect the physical world and virtual world (*e.g.*, human-computer interaction and holography communications). Moreover, MRIL consists of MaaS model layer and virtual multi-dimensional resource pool built upon Metaverse. Specifically, MaaS model layer is composed of the MaaS models while the resource pool consists of the virtual resources mapped from the physical world. 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. In Slicing4Meta, based on QoE requirements of Metaverse users, we classify two major types of Metaverse services including AR/VR services and digital twin services. The businesses and operators support specific types of Metaverse services by creating and managing specific MSI clusters that form a complete instantiated logic virtual network. Additionally, the AI layer consists of some local AI controllers and a global AI controller, where AI technologies is integrated into the controllers to intelligently manage and orchestrate various MaaS models to support them. In the following, we give the details of instantiating Metaverse services and illustrate where and how AI can be incorporated.

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 service 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 Management and Orchestration 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 to modify existing MSIs and MaaS models and/or create new MSIs and MaaS models.

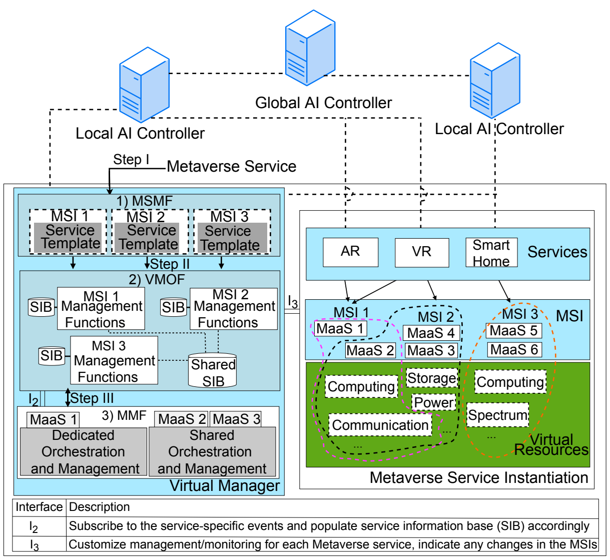

Fig. 3. Instantiation of Metaverse service

D. Intelligent MSIs Integration of Slicing4Meta

Managing and orchestrating 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 Slicing4Meta framework, businesses/operators can intelligently create and manage MSIs intra-/inter- clusters at a relatively low CAPEX/OPEX. 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 MSIs that consist of 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.*,

TABLE I
METAVERSE SCENARIOS, QOE REQUIREMENTS, AND THE CORRESPONDING MAAS MODELS AND MULTI-DIMENSIONAL RESOURCES

Service Type	QoE Requirements	Metaverse-as-a-Service (MaaS)		Multi-dimensional Resources	Metaverse Scenarios
		Component-as-a-Service	Technology-as-a-Service		
Digital Twin Services	Physical-virtual Synchronization Fidelity	Infrastructure/Platform/ Software/Hardware- -as-a-Service	AI-as-a-Service 3D modeling-as-a-Service Human-computer interaction technology-as-a-Service	Computing Bandwidth Protocol Stack	·Industry 4.0 ·Healthcare ·Smart City ·Manufacturing ...
	Service Quality	Cloud Server/Sensors- -as-a-Service	Communication Protocol- -as-a-Service	Bandwidth Computing	
AR/VR Services	Rendering Experience	Rendering Server-as- -a-Service	AI/Edge Computing- -as-a-Service	Rendering Capacity Computing	·Virtual Traveling ·Game ·Virtual Meeting ·Social Interaction ...
	Ultra-low Latency (below 1.5 ms)	Edge Server/Sensors- -as-a-Service	Edge/Fog Computing/ Cache-as-a-Service	Storage Computing	
	High Data Rates (peak: 1Gb/s)	Infrastructure/Platform -as-a-Service	Terahertz Communication- -as-a-Service	Bandwidth Spectrum	

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.*, peak data rates up to 1 Tb/s and user-experienced data rates up to 1 Gb/s) [4]–[6]. 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 basis, businesses and/or operators can reduce CAPEX/OPEX costs while meeting the requirements of the services. Under this circumstance, we classify the necessary MaaS models to support customized AR/VR services as follows:

(1) *CaaS*: First, AR/VR devices are the basic CaaS models to support feature tracking. Second, similar to DT services, software, platforms, infrastructures and hardware can be integrated as services to optimize user engagement. For example, AR visualization software can be integrated with AR Software Developer Kit (ADK) platform to create a personalized MSI model to meet the specific AR interaction experience.

(2) *TaaS*: AR/VR scenarios such as video shooting, game and social interaction, require highly dynamic and complex technologies to support latency-sensitive AR/VR services 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 traveling case study and corresponding simulation results in this section.

A. Metaverse Scenarios

We consider a basic AR/VR service that provides users virtual immersion experiences via virtual traveling [14]. In the following, we list necessary resources (also called capabilities) and the associated MaaS models that are needed to construct the traveling MSI:

- Computation, storage and communication resources. Guaranteeing fluid synchronization between Metaverse users' movements and visual perception is of importance for virtual traveling. 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 traveling 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 traveling MSIs.

• Data processing capabilities. (1) Data collection. The physical-virtual connection empowers the data collection process to update virtual representations (*e.g.*, traveling 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 simulated by virtual models based on the data collected from the physical world. To facilitate the data collection, device-as-a-service can create/modify device patterns to provide specific data collection capabilities and interaction protocols. (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 traveling monitoring. For example, 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. In addition, TaaS models such as edge computing-as-a-service should be integrated into specific MSIs to provide computing capabilities needed for the AI algorothms/technologies.

Undoubtedly, during the construction process of the traveling MSIs, some MaaS models provide multi-dimensional resources while others consume these resources. Therefore, before constructing specific MSIs via MaaS models, we need to quantitatively analyze the QoE when integrating multi-dimensional resources of various MaaS models for a specific traveling MSI. In this paper, similar to the idea of [15], we exploit a novel metric that consists of subjective service 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.

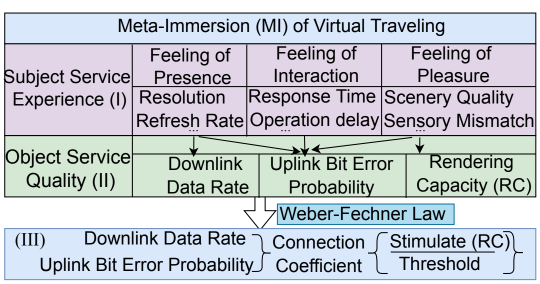

Fig. 4. Meta-Immerse of the virtual traveling

As shown in Fig. 4, for the QoE of virtual traveling services, the objective service quality is measured by the downlink rate, uplink bit error probability (BEP) and rendering capacity (Part II). Meanwhile, the subjective service 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 traveling, we establish the relationship between the objective service quality and the subjective service experience (Part III). Specifically, in virtual traveling, we use Weber–Fechner law to express the relationship between the stimulus of rendering experiences that travelers perceive from virtual traveling 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 traveling.

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 $\times$ 480 pixel resolution. Moreover, there are 56 virtual objects in the virtual traveling 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.

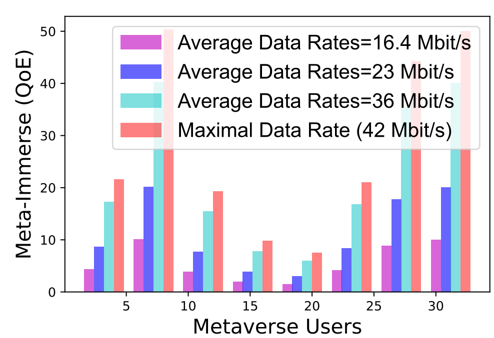

Fig. 5. Meta-Immerse under four different data rate constraints.

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

Under the Slicing4Meta framework, as multiple MSIs share the same MaaS models and occupy the same resources, the isolation of the customized MSIs may be broken.Therefore, besides the conventional physical isolation, some efficient solutions should be further explored to enhance the isolation of MSIs, including 1) logical isolation. Logical isolation is mainly to isolate various Metaverse service clusters. Indeed, both the global and local AI controllers can assist to solve logical isolation issues by monitoring and predicting data (*e.g.*, traffic variation and network states) to pre-deploy MSIs for Metaverse service clusters. Moreover, a certain logical isolation level for the type of Metaverse services is needed, where the lower the isolation level, the easier to share MaaS models. 2) Scheduling isolation. Scheduling isolation is mainly to isolate the required MaaS models for services. Similarly, AI controllers can pre-deploy MaaS models to enhance scheduling isolation by monitoring and predicting service flows.

B. Security and Privacy

Both the local and global AI controllers involve data interaction and processing. Once the controllers are maliciously attacked, severe security and privacy issues of mobile systems happen. Moreover, integrating MaaS models requires a large number of data interactions, which makes the service privacy more likely to be leaked, and the system more vulnerable. Fortunately, some emerging technologies with data protection have been widely investigated and can be exploited under the Slicing4Meta framework. Specifically, blockchain can be introduced as a service to guarantee system information security by implementing mature security authentication mechanisms. Indeed, each local AI controller can be regarded as a blockchain node, which can maintain the states and guarantee safe data interactions [7]. Additionally, some encrypted AI Algorithms such as federated learning can enforce AI-related security by keeping the data where it is generated. Furthermore, some protocol security services would help to protect individual privacy and guarantee data security.

VI. Conclusion

In this paper, we have proposed MaaS to provide on-demand subscription solutions for customizing Metaverse services. To unify the management and orchestration 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 traveling 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.

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