Metaverse Applications in Energy Internet

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***Abstract*—With the increasing number of distributed energy sources and the growing demand for free exchange of energy, Energy internet (EI) is confronted with great challenges of persistent connection, stable transmission, real-time interaction, and security. The new definition of metaverse in the EI field is proposed as a potential solution for these challenges by establishing a massive and comprehensive fusion 3D network, which can be considered as the advanced stage of EI. The main characteristics of the metaverse such as reality to virtualization, interaction, persistence, and immersion are introduced. Specifically, we present the key enabling technologies of the metaverse including virtual reality, artificial intelligence, blockchain, and digital twin. Meanwhile, the potential applications are presented from the perspectives of immersive user experience, virtual power station, management, energy trading, new business, device maintenance. Finally, some challenges of metaverse in EI are concluded.**

Keywords—metaverse, energy internet, virtual reality, artificial intelligence, blockchain, digital twin

I. Introduction

Energy internet (EI) is a new energy-information fusion network by deeply integrating the new generation energy system, communication technology, and internet concept. After several years of research and development of EI, it can effectively enhance the capability of power network management, enable energy sharing between microgrids, and improve the utilizing efficiency of distributed energy. However, the demand for energy exchange and information transmission has considerably increased, which brings new challenges of EI. For example, the different energy systems including electric-, coal-, gas- and oil-fired power systems cannot be synchronously interconnected, and the energy transmission is not that flexible and controllable just like information transmission in the Internet. In the commercial field, the energy network is still monopolized by a few large companies, thereby it is difficult to form a direct connection between many sources and loads. It means a large number of energy users unable to participate in the energy market in an open and peer-to-peer way.

In order to address these challenges, artificial intelligence (AI) technology has been used to solve the nonlinear problems in a complex energy network system. Neural networks and deep learning are widely applied in energy planning, scheduling, and transaction in EI [1]. Blockchain network is introduced into the scene of peer-to-peer energy trading to avoid transaction failure [2]. A Cyber-Physical Energy System (CPES) was proposed to monitor, analyze, plan, and execute the energy system by utilizing the digital twin concept [3]. Although AI, blockchain, digital twin, and other advanced technologies can partly solve the aforementioned challenges, the complete interconnection of EI is still constrained by a lack of a comprehensive platform.

The earlier concept of metaverse came from the science fiction Snow Crash in 1992, which established a virtual world by utilizing virtual reality devices. Thanks to the development of Information and Communications Technology (ICT), metaverse has achieved a qualitative leap in recent years. Nowadays, metaverse is not just a virtual space with real-time communication and immersive experience. It begun to penetrate from gaming and social communication to medical, industrial, and educational aspects. Since the persistence， comprehensiveness， accessibility， and decentralization are the unique characteristics of metaverse，the open and persistent connectivity platform can be explored to promote the development of EI based on metaverse. Thus， the development of metaverse concept of EI is of vital importance. However，the applications of the metaverse in the field of energy are focused on the modeling of digital counterpart of physical equipment and simulation of system operation now.

In this paper, we introduce the background knowledge of metaverse and the motivations and benefits for applying metaverse into EI are discussed. Furthermore, the major enabling technologies are summarized, which includes virtual reality, artificial intelligence, blockchain, and digital twins. Finally, potential applications of metaverse are discussed.

The rest of the paper is organized as follow: Section II presents a definition of metaverse and discusses the benefits for applying metaverse to EI. Section III discusses the four major enabling technologies of metaverse. Section IV displays the major applications of metaverse in EI. Section V analyzes the main challenges of metaverse. The conclusions are drawn in Section V.

II. Background Knowledge

In this section， we will mainly introduce the definition and characteristics of metaverse, and summarize the benefits of

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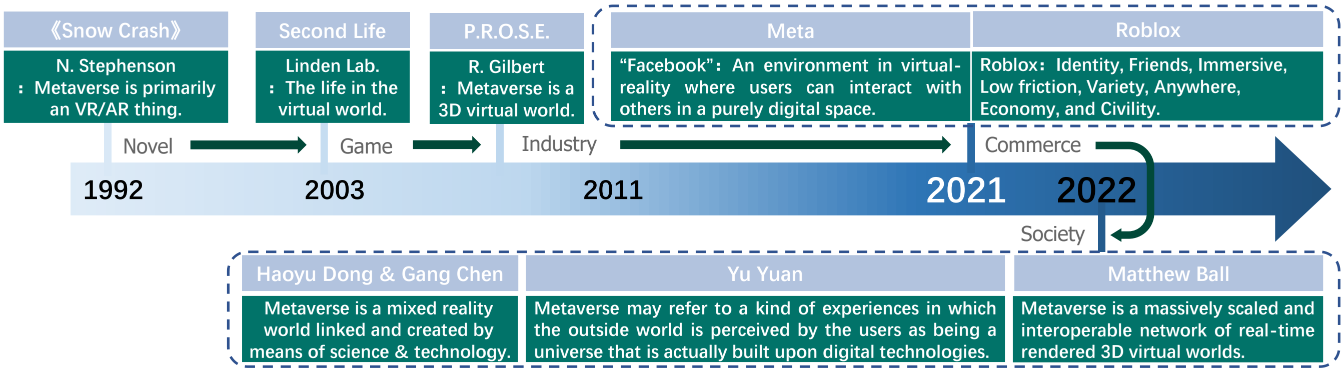


Fig.1. Development history of metaverse definition.

metaverse in EI from three aspects: information interconnection, virtual- reality integration, and business extension.

A. Definition and Characteristic of Metaverse

The development history of metaverse definition is shown in Fig.1. The people in the novel can live in a virtual world by utilizing virtual reality (VR) and AR technology. With the development of internet and videogames, Second Life was launched in 2003. It is commonly considered to be the first prototype of the metaverse due to the open, and pluralistic virtual society in the game. R. L. Gilbert proposed five basic characteristics of virtual world including 3D sensing, massive interaction, persistence, immersion, and content production [4]. In general, metaverse is described as a virtual game and individual virtual world based on VR in most cases before 2021. With the listing of Roblox in U.S.A, metaverse has achieved a qualitative leap. Roblox proposed eight characteristics including friend, immersive, low friction, variety, anywhere, economy, and civility to describe metaverse in a social perspective. Before long, Facebook was officially renamed for Meta and defined the metaverse from both social and commerce perspective. The resulting scientific attention and investment have opened a new era of metaverse. Consequently, metaverse platforms have been applied from gaming to social activities and industry. Although the current scenarios are limited in capacity to provide immersive and real-time experience for users, the applications of metaverse will rapidly evolve and widely spread.

At present, metaverse is still in its early stages with an individual vision and there is no an exact and fully-fledged definition of metaverse. Matthew Ball presented that metaverse is a massively scaled and interoperable network of real-time rendered 3D virtual worlds [5]. Yu Yuan gave a definition of metaverse as a kind of experience as shown in Fig.1 and the characteristics are classified into three categories: shall, should, and may. In the journalism field, Dr. Dong proposed another definition: "Metaverse is a mixed reality world linked and created by means of science & technology, which reflected and interacted with the real world, and is a digital living space with new economic & social system. " [6].

In the EI field, metaverse is a massive and comprehensive fusion network which can provide real-time interaction and connection in the 3D virtual space through deep integration of energy, information, economy, and social system by utilizing next-generation ICT. In a broad sense, the metaverse of EI is the advanced stage and long-term vision of digital energy system.

Although the definitions of metaverse are different in different scenarios and perspectives, the key characteristics are similar including reality to virtualization (R2V), interaction, expansibility, persistence, decentralization, immersion, economy, and sociality as shown in Tab.I. Compared with Web 2.0, metaverse has distinct advantages of R2V, decentralization, and immersive experience. Users can experience more realistic virtual world and have the ownership of user-generated content. Due to the high fidelity modeling technology，the real world can be precisely mapped to virtual world by digital twin. However, the persistence cannot be guarantee and the expansibility is limited without synchronously information exchange between physical system and digital twins.

Tab. I Characteristic of metaverse in the EI field.

Characteristic	Web2.0	Digital Twin System	Metaverse
R2V	★	★★★	★★★
Interaction	★★	★★	★★★
Expansibility	★★	★	★★★
Persistence	★★	★	★★★
Decentralization	★	★	★★★
Immersion	★	★★	★★★
Economy	★★	★	★★★
Sociality	★★	★	★★★

B. Benefits for Applying Metaverse in EI

In the previous subsection, we introduced the definition and characteristics of metaverse in the field of EI, metaverse can provide a comprehensive platform to break down the traditional barriers of energy and improve the efficiency of communication. Moreover, it can bring huge development space and imagination space to the energy industry. The main benefits for applying metaverse in EI are summarized from three aspects:

1. Information Interconnection: Metaverse can significantly enhance the interconnection of information and energy. Human, physical energy system, and digital system has been intelligently connected. Information flows can be synchronously interconnected, persistently stored, and effectively exchanged. The visualization of data and the capacity of management are improved by the interconnection and integration of virtualization and reality in metaverse. In addition, it has greater effectiveness on improving the security and privacy issues due to the decentralization.

2. Virtual-Reality Interaction: The boundary between the virtual and the reality will become increasingly blurred with the development of VR, Augmented Reality (AR), Extended Reality (XR), and Mixed Reality (MR) technologies. No boundary interaction and operation in the virtual world gives energy and information strong ability of mobility and autonomy. Thus, the performance of real-time display, prediction, management, and control will be significantly improved by applying metaverse concept in EI.

3. Business Extension: Metaverse can provide an open economy system to improve the convenience and flexibility of energy production and consumption. The users will have a freedom of energy exchange and energy trading previously unknown. Meanwhile, based on business processes in traditional EI, the value chain of EI can be extended by the new virtual business and digital services.

III. Key Enabling Technoloies

The key technologies should correspond to the characteristics of the metaverse and play the most important roles in the establishment and maintenance of metaverse. Based on the proposed definition of metaverse in EI, we summarize four key enabling technologies: virtual reality, artificial intelligence, blockchain, and digital twin as shown in Fig.2.

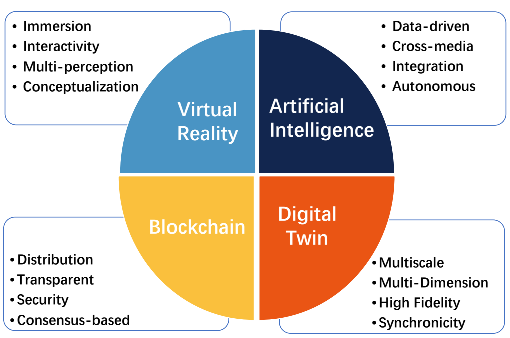


Fig.2. Key enabling technologies of metaverse.

A. *Virtual Reality*

VR is a practical technology developed in the 20th century. Through 3D graphics technology, multimedia technology, simulation technology, display technology and others, the computer can produce a realistic 3D vision, tactility, smell, taste and other sensory experience of the virtual world, so that people in the virtual world have an immersive feeling. The maturity of immersive technologies such as VR, AR, XR, and MR are the prerequisite for the realization of metaverse. The features of VR in metaverse include: immersion, interactivity, multi-perception, and conceptualization as shown in Fig.3.

The main applied technology of VR can be divided into five aspects: dynamic environment modeling technology, real-time 3D graphics generation technology, stereoscopic display and sensor technology, development tools of application system, and system integration technology. In order to improve the performance of interaction, immersion, and fluency in metaverse, researchers generally adopt the combination technology scheme of VR in metaverse as shown in Fig.3. Two early-stage design projects are presented to establish stronger connections based on XR and Internet of Things (IoT) in [7]. An incentive mechanism framework is proposed to manage and allocate non-panoramic VR services between service providers and users in metaverse based on an efficient deep reinforcement learning method in [8]. Siyaev *et al.* [9] proposed mixed reality education and training of aircraft maintenance, which the speech interaction module is enhanced to help engineers better control virtual assets and workflow by utilizing smart glasses. By examining the technical capabilities of immersive VR, five affordances including embodiment, interactivity, navigability, sense-ability, and create-ability are proposed in Ref.[10]. Jeon *et al.* [11] discussed how individuals cognitively and emotionally process social media posts in metaverse platform.

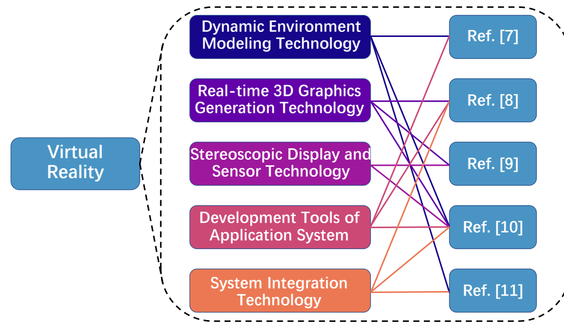


Fig.3. The combination technology scheme of VR in metaverse.

B. *Artificial Intelligence*

AI is a branch of computer science that attempts to understand the essence of intelligence and produce a new kind of intelligent machine which can respond in a similar way to human intelligence. Metaverse is the goal-oriented development of Artificial Intelligence (AI), and AI is the driving force for the development of metaverse. The features of AI in metaverse include: data-driven, cross-media, integration, and autonomous. The underlying framework based on AI will support human to create massive and fascinating superstructures in metaverse.

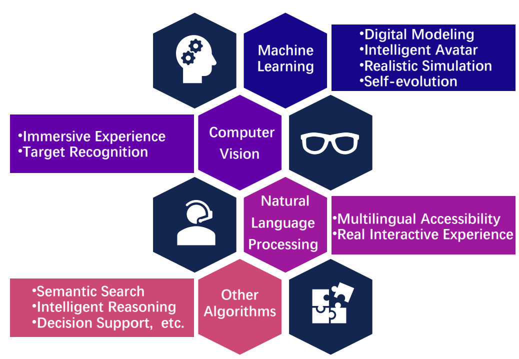


Fig.4. The application algorithms of AI in metaverse.

Based on the machine learning (ML), computer vision (CV), natural language processing (NLP), and other intelligent algorithms, the applications have been widely represented in metaverse, as shown in Fig.4. Huynh *et al.* [12] proposed a novel digital twin scheme supported metaverse by jointly considering the integrated model of communications, computing, and storage through the employment of mobile edge computing (MEC) and ultra-reliable and low latency communications (URLLC). Njoku *et al.* [13] introduced data-driven intelligent transportation systems (DDITS) and presented two major case studies of metaverse applications to DDITS: the invisible to visible (I2V) and the Metaverse on Wheels (MoW) technologies. Lee *et al*. [14] proposed a brain-to-speech (BTS) system for real-world smart communication using brain signals, which can be one of the future applications of brain Metaverse system. Li *et al*. [15] provided an approach to 360-degree panoramic VR football teaching based on machine learning and K-means algorithm. Zhu *et al*. [16] proposed a flexible Metaverse AI technology framework (MetaAID) that aims to support language and semantic technologies in the development of digital twins and virtual humans.

C. Blockchain

Blockchain, also called a distributed ledger, owns consecutive blocks, which are linked with each other through the hash value of the previous block header. Blockchain is a distributed database or ledger that is shared among the nodes of a computer network. As a database, Blockchain stores information electronically in digital format. The Blockchain network has the following property: distributed、secure、transparent、consensus-based、flexible.

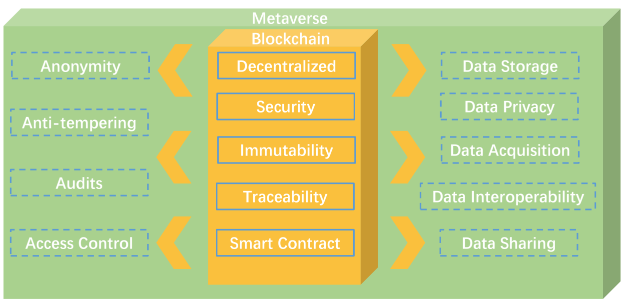


Fig.5. The applications of blockchain in the metaverse

Blockchain acts as a key enabler for data service and socio-economic systems in metaverse. More and more scholars are beginning to apply blockchain in metaverse. The blockchain uses asymmetric-key encryption and hash functions which ensure the security of data in the metaverse [17]. Kang *et al.* [18] proposed a privacy-preserving framework for data training by federated learning (FL) on both virtual space and physical space of the industrial metaverse. Cross-chain technology is utilized to design a decentralized FL architecture with the main chain and multiple sub-chains for secure model training. There are no third-party middlemen allowed to abuse or obtain data from other parties in the blockchain-powered metaverse in [19]. With the asymmetric key and digital signature mechanisms, blockchain can enhance the users' privacy and anonymity in [20]. Mozumder *et al.* [21] discussed the technological roadmap of Metaverse technology and the medical domain activity of the Metaverse. Blockchain provides a data platform with extremely high security, enabling different companies to share data in [22]. The application of Blockchain in the metaverse is shown in Figure 5.

D. Digital twins

Digital Twin was originally proposed by Michael Grieves as an integrated multi-physics, multiscale, probabilistic simulation of physical system. In metaverse, digital twins can be considered as a digital counterpart of the physical world. Based on the data sampling and data processing, the digital twins can be real time established and simulated, such as digital model, digital object and digital scenarios. The applications of monitoring, exhibition, prediction, management, design, simulation, and training are driven by the twin data from digital twins as shown in Fig.6. Meanwhile, metaverse will give the physical world and digital twins feedback to interact and coordinate each other. Thus, features of high-fidelity, real time synchronization, and faithful mapping in digital twins can be guaranteed by iterating, interacting and optimizing.

Nowadays, digital twin concept has been attracting increasing attention. Han *et al.* [23] proposed a novel IoT-assisted synchronized data collection framework to address the problem of digital twin synchronization for the virtual service providers in the metaverse. Lv *et al.* [24] extracted the immutable characteristics of Blockchain and proposed a secure multidimensional data storage solution called BlockNet, which could ensure the security of the IoT digital mapping process, thereby improving the data reliability of digital twins. Han *et al.* [25] identified a resource allocation problem for virtual service synchronization selection in which the IoT devices in a particular region in the real world are hired by the metaverse. Saeed *et al.* [26] proposed a three-layer architecture, including physical layer, user interface layer, and metaverse layer.

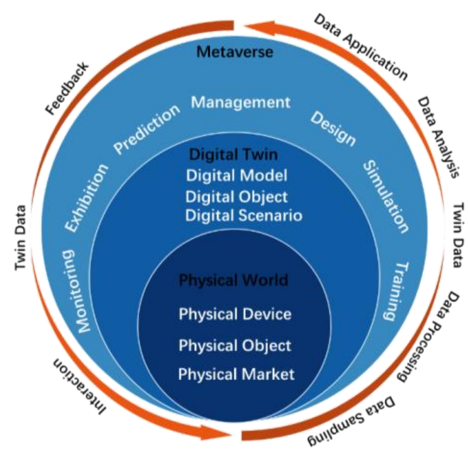


Fig.6. The approach of applying digital twin in the metaverse

IV. Applications In Energy Internet

Compared with the traditional EI, the network can self-evolute by applying for metaverse and people can be really immersed in EI. People can deeply immerse and synchronously interact with the different physical systems through the related technologies and devices including monitors, sensors, actuators, and avatars (that can be considered as a kind of virtual devices), as shown in Fig.7. We will further explore potential applications of metaverse in EI: immersive user experience, virtual power station, management, energy trading, new business, device maintenance.

A. Immersive User Experience

One of the advantages by applying metaverse is immersive sense and interaction for users. For personal users, when they enter into metaverse by the related devices, all the required information will be represented before their eyes. They can view their energy consumption, power production and power quality in real time. For energy system administrators and engineers ,

Fig.7. Applications of metaverse in EI

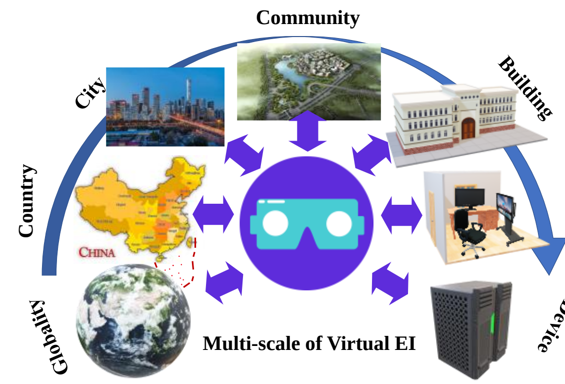
they can monitor and operate the power stations and grids anytime and anywhere. For marketing manager, the market operation will be more efficient and smooth because the sensitivity and perception range to the trading/exchange market are greatly enhanced in metaverse.

B. Energy Trading

Metaverse could fully support the energy transaction, payment and circulation in EI. The common approach of energy exchange and trading is using the reality assets to trade on the virtual trading platform. The other approach is to convert real-world assets into digital assets in metaverse, such as energy credits and digital currency. These digital assets can be used for energy trading and purchasing related energy services. Obviously, the advantages of utilizing blockchain for energy trading is more secure and flexible. It will not depend on traditional third part for billing and physical currency settlement, which is centralized and easy to be attacked. Moreover, it allows multi-parties be participate in the energy trading with a trustable co-governance environment, such as large power plants, composite polymerization side, and individual new energy supply side. With the advancement of metaverse, the energy trading market will be more free and open, while more and more innovative trading modes will be generated in metaverse.

C. Managment

Massive historical data and real-time data will be transmitted, stored and processed through communication and computing technologies. The virtual EI driven by knowledge and data will be continuously iterated and optimized through artificial intelligence algorithms. Finally, based on 3D and VR devices, the reality EI could be holographically mapped for users in the metaverse as a virtual EI, which has a complete information (e.g. production, transmission, storage, consumption and trading of all kinds of energy). The display scale of the virtual EI can be changed from globality to buildings, even to single room and electric device as shown in Fig.8. Consequently, holographic monitoring of EI can be realized and management efficiency can be predicted in the virtual EI. Moreover, process cycle management of energy, life cycle management of equipment, and energy planning can be more efficient and optimized.



D. Virtual Power Station

The virtual power station is a metaverse-based distributed energy management system. The virtual power station built based on the metaverse can provide users with a digital access space environment, and users can access the virtual power station environment anytime and anywhere to pay for power resources. Meanwhile, the virtual power station built based on the power station in the physical world can provide a safe scheduling implementation, and operation and maintenance environment for administrators, avoiding potential security risks in the real environment. More importantly, the virtual power station based on the metaverse is conducive to the experimental verification of new technologies and strategies, including efficient and energy-saving power supply schemes, power demand forecasting and heterogeneous power resources allocation technologies, and distributed energy management and control and integration strategies, etc. In general, the virtual power station based on the metaverse can provide a virtual but real platform for different roles involved in power transactions, including energy suppliers, users and operators, which is conducive to the construction of smart grids.

E. device maintenance

AR and digital twin technology create enormous opportunities for the immersive detection and remote diagnosis. Based on AR and VR technology, Inspectors can immersively monitor the equipment and infrastructure by operating UAVs, robots, and other monitoring equipment in metaverse, just like in the real world. Based on the high fidelity model and visual display technology, the 3D model and the precise real-time information of the device can be visually integrated and presented to the engineers and experts in real time, so that the precision and efficiency of device maintenance in EI can be significantly improved. In addition, the more comprehensive predictive maintenance of energy equipment and grid can be realized by utilizing the digital twin based on the multi-time scale and multi-granularity simulation.

F. New Business

Based on the virtual equipment and power grid in the metaverse, the education and training business for employees can also be extended according to the business process of EI. In the future, EI will further expand communication, computing and data storage business by utilizing the metaverse.

V. CHALLENGES

Although applying metaverse has huge potential and widest future, there are still many challenges to the realization of a fully-fledged metaverse in EI. Firstly, metaverse is still in the embryonic stage of concept definition, hardware research, and business exploration. The key enabling technologies and other support technologies, such as, 5G/6G and distributed computing, still need to be developed for a long time. Secondly, as a large-scale connected virtual reality network, data centers, computing centers, communication infrastructures and other infrastructures are necessary for metaverse application scenarios, which need the huge energy supply. Thus, the contradiction between energy supply and demand is likely to become more serious for applying metaverse in EI. Finally, it is more difficult and trickier for governments to deal with the privacy, security, and ethical issues in distributed virtual space because of the influx of personal privacy and business information into metaverse.

VI. CONCLUSION

The birth of metaverse will further promote the connection and integration of reality and virtuality, which will have a strong impact on the development of human society. In this paper, the development of metaverse is investigated firstly. We envisioned that applying for metaverse concept could be the potential solution to address the energy internet challenges by constructing a massive and comprehensive fusion network, which can deeply integrated energy, information, economy, and social system. Compared with Web 2.0 and digital twin system, the main characteristics of metaverse in energy internet are discussed. After then, the key enabling technologies of metaverse, including virtual reality, artificial intelligence, blockchain, and digital twins are introduced in details. Then, we proposed the potential applications of metaverse in six different scenarios. In addition, we discussed some research challenges of metaverse. We believe that the advancements in brain-computer interface, artificial intelligence, communications, data centers, and other information technologies are the enablers that will make the implementation of the mature metaverse possible.

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