Metaverse

Communication and Computing Networks

Applications, Technologies, and Approaches

Edited by

Dinh Thai Hoang | Diep N. Nguyen

Cong T. Nguyen | Ekram Hossain | Dusit Niyato

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To my family
— Dinh Thai Hoang

To my family
— Diep N. Nguyen

To my family
— Cong T. Nguyen

To my parents
— Ekram Hossain

To my family
— Dusit Niyato

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Editors' Biography

Dinh Thai Hoang received his PhD degree from the School of Computer Science and Engineering, Nanyang Technological University, Singapore, in 2016. He is currently a faculty member at the University of Technology Sydney (UTS), Australia. Over the past 10 years, he has significantly contributed to advanced wireless communications and networking systems. This is evidenced by his excellent record with one patent filed by Apple Inc., two authored books, one edited book, four book chapters, more than 80 IEEE Q1 journals, and 60 flagship IEEE conference papers in the areas of communications and networking. Most of his journal papers have been published in top IEEE journals, including IEEE JSAC, IEEE TWC, IEEE COMST, and IEEE TCOM. Furthermore, his research papers have had a high impact, as evidenced by nearly 14,000 citations with an h-index of 44 (according to Google Scholar) over the past 10 years. Since joining UTS in 2018, he has received more than AUD 3 million in external funding and several precious awards, including the Australian Research Council Discovery Early Career Researcher Award for his project "Intelligent Backscatter Communications for Green and Secure IoT Networks" and IEEE TCSC Award for Excellence in Scalable Computing for Contributions on "Intelligent Mobile Edge Computing Systems" (Early Career Researcher). Alternatively, he is the lead author of two authored books, "*Ambient Backscatter Communication Networks,*" published by Cambridge Publisher in 2020 and "Deep Reinforcement Learning for Wireless Communications and Networking," published by IEEE-Wiley Publisher in 2022. He is currently an Editor of IEEE TMC, IEEE TWC, IEEE TCCN, IEEE TVT, and IEEE COMST.

Diep N. Nguyen is a faculty member of the Faculty of Engineering and Information Technology, University of Technology Sydney (UTS). He received ME and PhD in Electrical and Computer Engineering from the University of California San Diego (UCSD) and the University of Arizona (UA), respectively. Before joining UTS, he was a DECRA Research Fellow at Macquarie University, a member of technical staff at Broadcom (California), ARCON Corporation (Boston), consulting the Federal Administration of Aviation on turning detection of UAVs and aircraft, US Air Force Research Lab on anti-jamming. He has received several awards from LG Electronics, the University of California San Diego, the University of Arizona, US National Science Foundation, and Australian Research Council, including nominations for the outstanding RA (2013) awards, the best paper award at the WiOpt conference (2014), Discovery Early Career Researcher Award (DECRA, 2015), and outstanding Early Career Researcher award (SEDE, University of Technology Sydney, 2018). His recent research interests are in the areas of computer networking, wireless communications, and machine learning application, with an emphasis on systems' performance and security/privacy. Dr. Nguyen is a senior member of IEEE and an editor/associate editor of the *IEEE Transactions on Mobile Computing*, *IEEE Access, Sensors* journal, and *IEEE Open Journal of the Communications Society* (OJ-COMS).

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Dusit Niyato is a professor at the School of Computer Science and Engineering, Nanyang Technological University, Singapore. He received BE from King Mongkuk's Institute of Technology Ladkrabang (KMITL), Thailand, in 1999 and a PhD in Electrical and Computer Engineering from the University of Manitoba, Canada, in 2008. Dusit's research interests are in the areas of distributed collaborative machine learning, the Internet of Things (IoT), edge intelligent metaverse, mobile and distributed computing, and wireless networks. Dusit won the Best Young Researcher Award of IEEE Communications Society (ComSoc) Asia Pacific and the 2011 IEEE Communications Society Fred W. Ellersick Prize Paper Award and the IEEE Computer Society Middle Career Researcher Award for Excellence in Scalable Computing in 2021 and Distinguished Technical Achievement Recognition Award of IEEE ComSoc Technical Committee on Green Communications and Computing 2022. Dusit also won a number of best paper awards, including IEEE Wireless Communications and Networking Conference (WCNC), IEEE International Conference on Communications (ICC), IEEE ComSoc Communication Systems Integration and Modelling Technical Committee, and IEEE ComSoc Signal Processing and Computing for Communications Technical Committee 2021. Currently, Dusit is serving as editor-in-chief of IEEE Communications Surveys and Tutorials, an area editor of IEEE Transactions on Vehicular Technology, editor of IEEE Transactions on Wireless Communications, associate editor of IEEE Internet of Things Journal, IEEE Transactions on Mobile Computing, IEEE Wireless Communications, IEEE Network, and ACM Computing Surveys. He was a guest editor of the IEEE Journal on Selected Areas on Communications. He was a distinguished lecturer of the IEEE Communications Society for 2016–2017. He was named the 2017–2021 highly cited researcher in computer science. He is a fellow of IEEE and a fellow of IET.

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Preface

Recently, Metaverse has gained paramount interest and huge investment from the tech industry. Microsoft acquired Activision Blizzard for $70 billion in 2022 to set its first footsteps in the Metaverse game development race. Along with its huge investment in AR, one of the core technologies of Metaverse, Google has invested $39.5 million in a private equity fund for all Metaverse projects. Nvidia has created Omniverse, a developing tool for Metaverse applications. Besides huge investments from big tech companies, the economic activities of virtual worlds are also significant, with transactions that exceed the magnitude of millions of dollars. As a result, there is no doubt that the Metaverse will become one of the most prominent directions of development in both industry and academia. However, the development of the Metaverse, especially in academia, is still in a nascent stage. Currently, researchers are striving to judge the shape and boundary of the future Metaverse. They are only able to envision some of its possible characteristics, such as open space, decentralization, human–computer interaction experience, digital assets, and digital economy. Moreover, Metaverse applications are expected to face various challenges such as massive resource demands, ultralow latency requirements, interoperability among applications, and security and privacy concerns. Given the above, this book aims to provide a comprehensive overview of Metaverse and discuss its enabling technologies and how these technologies can be utilized to develop Metaverse applications.

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Introduction

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The term “Metaverse” refers to next-generation Internet applications that aim to create virtual 3D environments where humans can interact with each other and the applications’ functionalities via digital avatars. Although the original concept dates back to 1992, Metaverse has recently attracted paramount attention due to the huge potential to rival, or even replace, conventional Internet applications in the near future.

However, the development of the Metaverse, especially in academia, is still in a nascent stage. Currently, researchers are striving to judge the shape and boundary of the future Metaverse. They can only envision some of its possible characteristics, such as open space, decentralization, human–computer interaction experience, digital assets, and digital economy. Moreover, Metaverse applications are expected to face various challenges, such as massive resource demands, ultralow latency requirements, application interoperability, and security and privacy concerns.

Given the above, this book aims first to introduce the emerging paradigm of Metaverse, which is expected to pave the way for the evolution of the future Internet. The book also provides a comprehensive review of the state-of-the-art research and development covering different aspects of Metaverse for a wide range of readers, from general readers to experts. Advanced knowledge including innovative models, techniques, and approaches to overcome the limitations and challenges in developing Metaverse are then discussed. Finally, emerging applications of Metaverse are presented, along with the related challenges and open issues.

1

Metaverse: An Introduction

Lik-Hang Lee[1], Dimitris Chatzopoulos[2], Pengyuan Zhou[3], and Tristan Braud[4#]

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After reading this chapter you should be able to:

- Understand the current trends and challenges that building such a virtual environment will face.
- Focus on three major pillars to guide the development of the Metaverse: privacy, governance, and ethical design and to guide the sustainable yet acceptable development of the Metaverse.
- Illustrate a preliminary modular-based framework for an ethical design of the Metaverse.

1.1 Introduction

The term "Metaverse" was first introduced to the public in 1992 by Neal Stephenson in his work of science fiction, "Snow Crash." The main characters of the book are shown to coexist with their avatars in a world that is an integration of the virtual and the real, and it is populated by persistent virtual entities that are superimposed on our actual surroundings. People are able to execute a wide variety of immersive activities in this integrated reality.

# All authors equally contributed to this chapter.

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Several noticeable instances of this trend include people getting together with their friends in a different location, working jointly with their coworkers, and participating in shared virtual experiences (e.g. dating and virtual fitting). In other words, diverse digital or virtual contents originating from cyberspace will eventually go beyond the boundary of 2D displays in the Internet that we are now using and gradually make their way into three-dimensional (3D) settings.

As was said before, coincidentally, the projected environment is congruent with Mark Weiser's vision of ubiquitous computing in 1991: computer services would be integrated into a multitude of facets of our lives, and users will have access to virtual information whenever and wherever they choose. With such a compelling vision, the landscape of ubiquitous computing has been advanced throughout the course of the previous three decades by the proliferation of computing devices. These computing devices include laptop computers, smartphones, the Internet of Things (IoTs), and intelligent wearables.

According to Milgram and Kishino's Reality-Virtuality Continuum [16], the current cyberspace has undergone significant development in recent years, and recent attempts have been made to provide human users with services and digital experiences by means of virtual environments such as augmented reality (AR) and virtual reality (VR). Although no one can say for certain what the Metaverse will bring about once it is fully realized, recent pre-metaverse apps have most likely identified AR and VR on smartphones as the major testbed for immersive user experiences. Pokémon Go, for example, has become the most popular AR program on ubiquitous smartphones, astoundingly with 1 billion downloads, while Google Cardboard is bringing VR content to mainstream audiences (for example, YouTube VR) [4].

As such, the term "Metaverse" refers to a blended space at the intersection between physical and digital in which multiple users can concurrently interact with a persistent and unified computer-generated environment, and other users. This space has the potential to become the next important milestone in the development of cyberspace as it exists today.

It is worth noting that modern devices that enable entrance to Metaverse get access to multiple types of users' data. Also services based on artificial intelligence (AI) use derivatives of data generated by users in their function, making data the new commodity that spawns a lucrative, fast-growing industry.

This introductory chapter focuses primarily on discussing the evolution of the Metaverse as well as the difficulties that have been encountered. First, we will provide a concise overview of the evolution of cyberspace as well as the importance of technological enablers. As a result, our bottom-up methodology places an emphasis on the following three crucial technological enablers for the Metaverse: networks, systems, and users. In addition, we emphasize a number of essential challenges, both from a technical and an ecosystemic point of view, that are necessary for the construction and maintenance of the Metaverse.