Metaverse for 6G and Beyond: The Next Revolution and Deployment Challenges

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Abstract

Metaverse is an evolving paradigm for the next-generation Internet, intends to provide 3D immersive experiences and self–sustaining virtual shared space by utilising a wide range of relevant technologies. Due to rapid advancement in technologies such as augmented reality (AR), mixed reality and virtual reality (VR) in real-time applications, metaverse is proceeding from science fiction to extended reality (XR). In this article, we present the vision of metaverse's future in wireless technologies, including 6G and beyond. We illustrate the framework of metaverse-based wireless systems, describing the requirements and fundamental technologies to be integrated with 6G to realize the metaverse. We consider a case study of an autonomous vehicle's remote assistance system that leverages VR technology, 360° live stream, and a mobile edge-enabled distributed computing paradigm. The simulation findings demonstrate the effectiveness of employing VR technology to create an immersive environment for remotely controlling and supporting autonomous vehicles to enable quicker decision-making. Furthermore, we compare several potential future networks, discuss the deployment challenges, and present cloud-edge-end framework-driven solutions to employ Next-G wireless systems in the metaverse. Finally, we outline several open research directions to realize the true vision of metaverse towards 6G and beyond.

Introduction

Metaverse is a combination of the prefix "meta" (means beyond) and the suffix "where a third" (from the universe) is the next-generation Internet paradigm wherein users interact with software applications and other users as avatars in a three-dimensional (3D) virtual world, focusing on social connections. The term "metaverse" was first used by Neal Stephenson in his science fiction novel Snow Crash in 1992, where humans use virtual reality technology to enter the metaverse [1]. Metaverse has re-emerged as a buzzword after more than twenty years as "the successor of mobile Internet." With the aid of virtual reality (VR), augmented reality (AR), human-computer interfaces (HCI), and tactile Internet, users can experience a unique existence in virtual space in the metaverse like the real world [2]. Since its inception, the idea of the metaverse has been described in a variety of ways, including second life, augmented reality, 3D virtual worlds, life-logging, digital humans, and mirror worlds.

Currently, metaverse has considerably contributed to numerous industrial applications. Thus, various tech giants such as Facebook, Microsoft, and NVIDIA are willing to invest in its applications. In October 2021, Facebook changed its name to Meta, announced by Mark Zuckerberg who plans to invest 10 billion dollars toward the creation of the metaverse [3]. Using metaverse, Microsoft has recently acquired a video game-based company. In 2022, NVIDIA announced its first virtual and 3D design collaboration platform called NVIDIA Omniverse cloud to create and experience the metaverse. Thus, the metaverse is a promising solution that integrates key technologies such as AR, VR, and MR as extended reality (XR) in a global context [2].

The concept of the metaverse has been around for decades but has recently gained popularity. It was developed immediately after the invention of the Internet. Figure 1 depicts the timeline of the metaverse's development which includes several significant events, including the invention of the Internet in 1991, to the creation of the first virtual world with Second Life in 2003, and more recent metaverse initiatives from major technology firms such as Microsoft and Facebook. Thus, the metaverse will continue to evolve and grow in the next several decades.

To ensure a consistent experience across different virtual worlds, standards have been developed to ensure inter-operability and compatibility. The most predominant standards are OpenMetaverse, virtual reality modeling language (VRML), extensible 3D (X3D), and collaborative design activity (COLLADA) [4]. OpenMetaverse is an open-source framework based on the OpenSim protocol that provides a set of application programming interfaces (APIs), libraries, and tools for creating and interacting with virtual worlds. VRML is an open, 3D graphics standard to create and manage interactive 3D worlds. X3D is an open, XML-based 3D graphics standard to create interactive 3D worlds [5]. COLLADA is an open, XML-based 3D file format, which is used to exchange 3D assets between different applications, and to create 3D models and animations. Thus, OpenSim Protocol is used to transfer data between different virtual worlds, while VRML and X3D are used to create 3D scenes and objects [6]. COLLADA is used to exchange 3D assets whereas OpenMetaverse is used to create entire virtual worlds. As a result, it is possible to develop a more immersive and interactive metaverse experience by understanding the different roles of each standard [7].

However, for the metaverse use cases to fully realize the capabilities of the massive virtual universe, they must satisfy specific requirements, including relatively low latency, high resource demands, application interoperability, and security concerns. To meet the demands of higher data rates, ultra-reliable low latency communication (URLLC), and Internet-of-Everything (IoE) services, 5G networks have already been deployed which will facilitate a plethora of services. This would include ultra-reliable, low-latency communications, enhanced mobile broadband (eMBB), and massive machine-type communications (mMTC) with 20 Gb/s peak data rate. Although 5G has mmWave frequency bands feature, it cannot support the Tb/s-level data speeds and microsecond-level latency needed for the next generation of virtual augmented reality (VAR), IoE services, brain-computer interfaces, and connected autonomous systems.

To overcome these challenges, 6G is envisioned as an emerging revolutionary wireless technology and cutting-edge network

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architecture for tactile and haptic applications to provide high bandwidth, reliability, latency, energy efficiency, and intelligent services. 6G systems will increase the performance and maximize the user quality of service (QoS) more than 5G. It is also expected to be a global communication facility with approximately 1 Tb/s user bit rate with less than 1 microsecond latency. In this context, mobile edge computing (MEC) is also considered a fundamental technology for the transition to 5G and 6G networks. This is because it combines cloud computing with the Internet service environment at the edge of the network to offer a more efficient mobile network. The user experience is enhanced by MEC's focusing on proximity to the user, reduced network operation, and service delivery latency.

Furthermore, metaverse for emerging next-generation wireless systems has attracted significant research attention. In [1], the authors presented an extensive survey to describe the key roles and applications of blockchain in the metaverse. It has been identified that blockchain has great potential for preserving digital data and maintaining integrity in a distributed environment. In [2], the authors presented an overview of metaverse-based solutions for educational use cases and the role of IoE and XR in the metaverse for education, training, and skill development. Despite the advancements in the world of the metaverse, security and privacy risks remain the primary concern to its further development [3]. As a result, it's essential to use AI and blockchain technology to promote the self-governance capabilities of metaverse communities to report violations [4, 5].

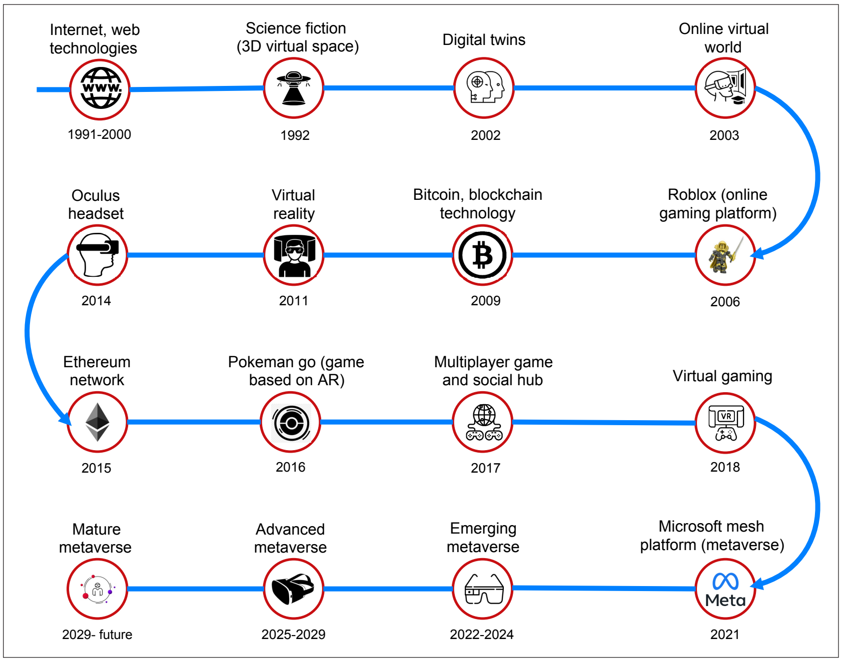

FIGURE 1. Timeline revolution in metaverse.

The post-pandemic era has seen a significant foundational shift in the healthcare sector that led to increased acceptance of virtual healthcare systems and related digital advances [6]. Therefore, incorporating the metaverse into a virtual healthcare system offers new techniques for delivering improved treatment at lower costs [7, 8]. In [9, 10] the authors discuss key applications and related technological advancements that will enable 6G systems to provide a comprehensive, forward-looking vision for a 6G network. In addition, the authors of [11, 12] identify the potential of a metaverse in urban planning to redefine the city design and provision of services to improve urban efficiency. Thus, it is projected that the metaverse will influence the quality of life. In [13], the author studied the use of VR technology utilizing video streams for controlling remote services. The author evaluated the latency of live streams of varying bitrates and protocols and found that pushing the real-time messaging protocol (RTMP) stream to the server yields the lowest latency. In [14], the author presents two use cases that require live video streaming services namely remote driving and platooning. The author also implemented and evaluated a live video streaming solution that provides low end-to-end latency during handover operations in both cloud and fog-based systems. However, existing studies have not explored deployment challenges and issues of integrating 6G in metaverse applications [15]. Therefore, in this article, we study how the 6G and beyond wireless network may benefit and enhance the metaverse because of its complex nature.

Contributions of this Work

We summarize the key contributions of this work as follows:

- We propose a layered reference model of metaverse and how to integrate metaverse with 6G wireless network. The reference model illustrates the relationship between different components in the metaverse that supports real-time user interactions between the physical and the virtual space.
- We discuss the deployment challenges associated with the integration of 6G in metaverse applications alongwith proposed solutions.
- We demonstrate, using a simulated case study, how to assess remote augmented reality help for improving the end-to-end latency of self-driving cars' performance.
- Finally, we analyze the performance of VR technology in decision-making by considering a use case of a connected_autonomous vehicle in an emergency situation. We use end-to-end latency in our performance evaluation study for different scenarios such as bitrates in terms of stream capture, encoding, and display time.

We organize the remainder of this article as follows. We present the proposed system model. We present a case study which includes a performance evaluation on how augmented reality can help self-driving cars. We discuss the deployment challenges and proposed solutions on how to integrate 6G in the metaverse ecosystem. Finally, we make some concluding remarks.

Proposed System Model

Layered Metaverse Architecture

Metaverse is one of the most significant and promising smart applications in the emerging next generation sixth-generation (6G) wireless systems. Hence, we propose a high-level layered architecture of the metaverse as Fig. 2 shows. This architecture describes the relationships between the different components in the metaverse, which support real-time user interactions between the physical and the virtual space.

Physical space: The physical world has fundamental requirements such as end devices and cloud/edge servers for supporting the operations of a virtual environment in the metaverse. It facilitates interactions between the human and digital worlds by integrating multisensory data perception, communication, processing, storage, and physical control. Intelligent devices such as VR head-mounted displays (HMDs), holographic displays, smart glasses, and haptic sensors can provide a fully immersive and interactive user experience. In the physical space, IoT devices are connected to metaverse applications to extract data from the real world and implement it into the virtual one. The communication infrastructure provides networking consisting of different heterogeneous wired or wireless networks. Also, the computation and storage capacities are distributed through the computation and storage infrastructure by using cloud/edge computing.

Social space: The metaverse represents a new era in the evolution of human social systems where humans can pursue higher-lev-

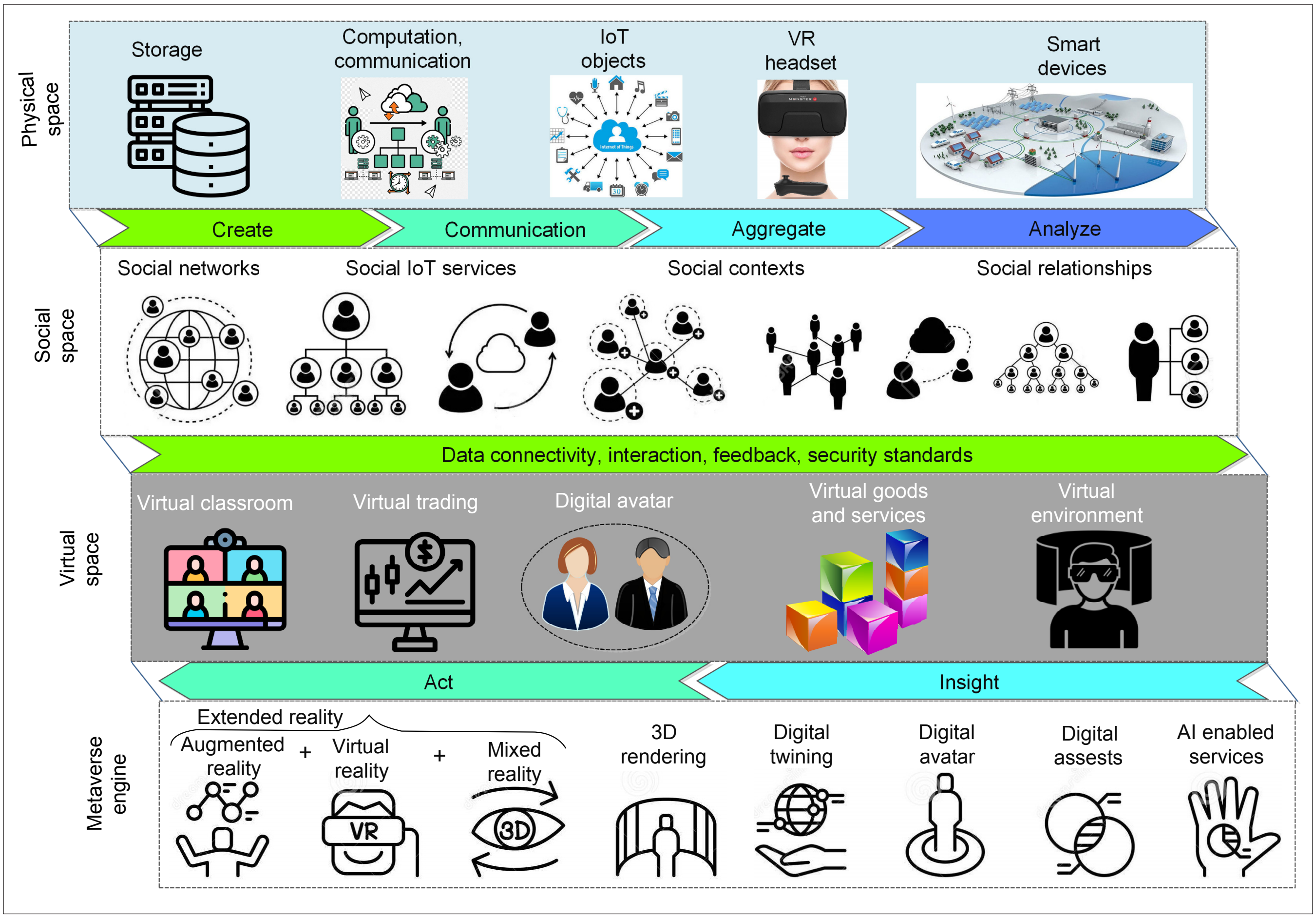

FIGURE 2. Layered reference model of metaverse.

el needs beyond those of the real world such as social interactions, virtual work environments, and entertainment. In addition to traditional social networks, it creates a social network and integrates with the user's social context provided by social IoT services, where a "third place" experience can be offered by the metaverse for immersive social life for social interactions, gaming, shopping, movies, e-sports, and activities. As a result, the metaverse will transform the way we communicate with social networks by eliminating a single access point and utilizing VR technology to build a 3D reality.

Virtual space: The physical and social entities in the metaverse are mapped into the virtual environment through APIs, which enable users to interact between the physical and virtual worlds. The physical layer provides the network infrastructure and computing resources, and the social layer provides the necessary connectivity between users in the metaverse. The virtual space of the metaverse includes a virtual environment for education, trading, goods and services, and the digital representations of human users as avatars. This environment is created and maintained using high-definition rendering and simulation technologies to give users a highly immersive experience. Similar to going shopping in a real environment, here users can also purchase virtual goods, and clothes from the providers for an interactive experience.

Metaverse engine: The metaverse engine acquires data from the stakeholders that are originally created and maintained by entities in the real and virtual worlds, to perform computations of a 3D model and other aspects of the virtual universe. It also facilitates interactions among digital twins, avatars, and interactive experience technologies which are either implemented at the edge or in the cloud.

Extended reality (XR): Extended reality is an umbrella term that integrates virtual reality, mixed reality, and augmented reality to provide revolutionary experiences through multisensory large-scale 3D rendering using XR devices. VR provides a visual experience in a truly immersive digital world and AR offers graphics, audio-visual, and holographic experiences overlaid in the real world, MR provides a transition between the two [5]. Thus, AR and VR are the essential components to achieve the objective of a 3D immersive metaverse experience in both the physical and the digital worlds.

Digital twin: A near-real-time replica of physical entities to digital or virtual models through modeling and data fusion. Digital twins can use AI and data analytics to incorporate intelligence into the metaverse for a better user experience, such as cognitive avatars and 3D object rendering. For instance, NVIDIA released GANverse3D, a framework powered by AI that can capture images of real entities and instantly create digital replicas [5].

The layers in the metaverse layered architecture interact with each other through the communication infrastructure to provide real-time user interactions between the physical and the virtual space. They are connected through a data exchange layer, which facilitates the sharing of data between the physical and virtual worlds. The security and privacy protocols ensure secure data exchange and data integrity. By applying data analytics to the data stored in the cloud/edge servers, we get gain further insights into how to to efficiently personalized services to the users. Thus, digital twin technology will optimize business performance using real-time IoT data and will facilitate new services and social interactions.

Table 2 summarizes the comparison of next-generation enabling technologies that might partially fulfil the metaverse communication requirements. The metaverse activities generate enormous amounts of data when millions of users communicate with one another, and significant network bandwidth is also needed to transmit high-resolution 3D animations. However, in the metaverse, the aforementioned technologies are

Key areas	Challenges	Technology and techniques used	Applications	Future directions
Security and privacy	• Privacy in metaverse games, digital footprints threats, accountability threat. • Pervasive data collection, digital-twin synchronization, data dissemination threat. • Insecure augmented reality content sharing • Eavesdropping, cursor-jacking, blind spot attack. • Man-in-the-middle, impersonation, denial-of-service attack. • Authentication and access control.	cloud computing, edge computing, blockchain, container-based virtualization, sandbox webVR, machine learning algorithms, hierarchical game theory, fuzzy vault, low-cost authentication in wearable devices, proxy encryption, smart contract.	vehicular communication, healthcare system, smart grid, automobile industry.	reliable security mechanisms for data transmission, data processing, edge/cloud storage, energy-efficient, content-centric, cloud-edge orchestrated metaverse, scalability of consortium blockchain for Internet of vehicles.
TeraHertz (THz) band frequency	• Path losses • Transceivers design with a wide operating bandwidth • Frequency modulation • Inter-modulation distortion • Antenna directivity	pulse laser beams spectrum allocation, hierarchical bandwidth modulation, distance adaptive absorption peak modulation.	airports, cancer detection, information communication technology (ICT), and high-definition (HD) pictures.	inter-band interference, spectrum efficiency, secure data sharing.
TeraHertz (THz) beamforming	• Amplifiers design that operate in THz bands with wide frequency • Channel modeling • Noise modeling • Dynamic channel with low multiplexing	massive multiple input-multiple output (MIMO) antenna, millimeter wave (mmwave).	ICT, product inspection, spectroscopy, imaging, radio communication.	energy-efficiency.
Device connectivity and interoperability	• Data security • Accommodating Tb/s data rates in AR, XR • Integration and device synchronization • Computation cost • Connecting device autonomously • Limited connectivity	Representational State Transfer (REST) APIs, cellular (5G/6G), Wi-Fi, bluetooth, zigbee, z-Wave, low-power wide area network (LPWAN), RFID.	healthcare system, telecommunication, automobile industry, smart grid.	wireless connectivity, capital expenditure and operational expenditure, cross-domain interoperability.
Latency and resource management	• Massive scalability • Massive connectivity • End-to-end (E2E) slice orchestration • Dynamic traffic load • Intelligent decision-making • Ultra-high reliability	machine learning, deep learning, artificial intelligence, Internet of things, distributed ledger technology, blockchain, mm-wave software-defined networking (SDN), time-sensitive networks (TSN), network virtualization, kubernetes, dockers, containers.	unmanned aerial vehicles (UAVs), self-driving cars, smart transportation system, AR/MR/XR, brain-computer interfaces.	network slicing and orchestration, scalability, dynamic traffic load.
High energy consumption	• Cost-effectiveness • Faster battery depletion	federated learning, deep reinforcement learning, self-powered energy harvesting schemes, massive MIMO.	smart grid, vehicle-to-vehicle communication, intelligent robotics, smart city, AR, VR, telemedicine.	sustainable devices, power optimization for resource-constraint wearable devices.
Co-channel interference coordination	• Co-tier and cross-tier interference in heterogeneous networks (HetNets) • Hybrid interference • Drone interference inter-cell	massive multiple-input and multiple output (MIMO), HetNets, UAVs, device-to-device (D2D), relay node, software-defined radio access networks (SDRAN).	vehicle-to-vehicle (V2V) communication, defense.	co-channel interference in HetNets and UAVs.

TABLE 1. Deployment challenges of 6G in metaverse for integrating 6G in metaverse applications.

delay-sensitive and require extremely low latency. Therefore, 6G networks and beyond can provide opportunities for ubiquitous and intelligent services for large-scale metaverse devices.

In the next section, we demonstrate the effectiveness of employing VR technology to provide remote assistance for autonomous vehicles in emergencies and analyze the performance in terms of end-to-end latency at different bit_rates.

Performance Evaluation

We conducted simulation tests to evaluate how well remote augmented reality helps self-driving cars in urgent circumstances. The smallest and lightest 360° camera with four ultra-high precision optical lenses, Labpano Pilot one (EE), is used to assess AR technologies. It can record up to 8K mesoscopic 360° recordings and transmit a live 360° video stream over a 6G network. We used a quad-core Intel® i7 processor, 16 GB of RAM, and a GPU that supports NVENC running at 3.40 GHz to perform the simulation. The receiver device has an Intel i7-6700 3.40GHz processor, 16 GB of RAM, and an Intel HD 530 GPU as part of its system configuration. Simulations are carried out in the MATLAB Simulink environment for the analysis of the end-to-end latency of the system.

For the simulation, for the case study, we considered remotely controlling and assisting autonomous vehicles in a dangerous situation to show how AR technology can be used. To create a comprehensive image of its surroundings, the autonomous car makes use of a variety of sensor technologies, such as LiDAR, which transmits millions of laser beams each second. Radars are used by LiDAR to detect distant objects and their speed, while high-definition cameras pick up visual information such as traffic lights to help understand their surroundings. The autonomous vehicle is capable of 360°environment detection and can make

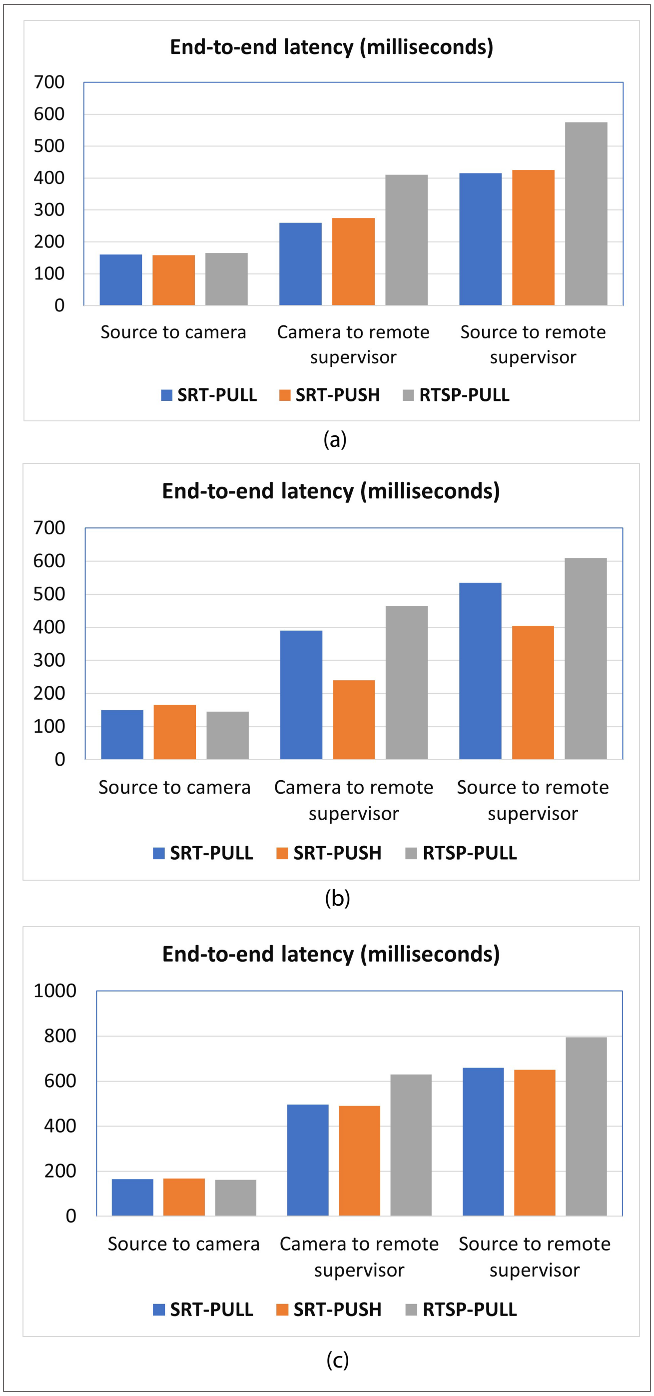

FIGURE 3. Compare the E2E latency at different bitrates in terms of stream capture, encoding, and display time: a) E2E latency at 6 Mb/s; b) E2E latency at 15 Mb/s; c) E2E latency at 30 Mb/s.

decisions to plan a safe course accordingly. The remote piloting supervisors are activated when the automated vehicle reaches its technological limits in dangerous situations or when it needs assistance. At that point, the camera on the autonomous car sends a 360°stream to the nearest server. The 360° panoramic view live stream with a head-mounted display, which offers a view of the entire 360°footage and promotes quicker reaction time, is fetched by the remote piloting supervisors as soon as they receive the notification. With the use of stream feedback, the remote supervisor decides whether to direct the vehicle to hurry up or slow down and offers a route that will transport it safely.

We used end-to-end latency as the performance metric in the delivery of 4K 360° live streams using 64-Quadrature Amplitude Modulation (QAM) and MIMO antenna configuration. We also evaluated the system performance at different bitrates of 6 Mb/s, 15 Mb/s, and 30 Mb/s for stream capture, encoding, and display time as Fig. 3 shows. The end-to-end latency is the time between the stream capture and display at the receiver side. In this study, the end-to-end latency is the sum of the following delay components: the first delay component is the delay at the camera screen for stream acquisition and encoding between the source location (camera lens) and the camera display. The second delay component is the delay for the stream to move from the camera to the remote supervisor's device display. The third delay component is the delay between the source and the remote supervisor's device. The streaming protocols used for the latency computation are Secure Reliable Transport (SRT) and Real Time Streaming Protocol (RTSP), i.e., SRT-PUSH, SRT- PULL, and RTSP-PULL. We used the SRT protocol because it outperforms the RTSP protocol in terms of performance and helps transport low-latency video streams safely and reliably over erratic connections. High-quality live video broadcasts are transmitted across the network with more flexibility using Dynamic Adaptive Streaming over HTTP (DASH) streaming technology. We used H.264 or a codec-independent compression format for 4K ultra-high-definition video. The Web Real-Time Communication (WebRTC) protocol over TCP is converted from the SRT or RTSP protocol by Oven-Media Engine, an open-source sub-second latency streaming server, so that the remote supervisor can view the 360° live video on a head-mounted display (HMD) device. The HMD device is an AR/VR headset that combines a voice-activated control system and a head-up display to help autonomous vehicles in an emergency. The camera and end-user screen displays are where the end-to-end latency is monitored.

Figure 3a shows the average end-to-end delay at a bitrate of 6 Mb/s and the RTSP protocol has a substantially higher latency than the SRT push and pull modes. We used the SRT push protocol in the first case, in which a camera is mounted to push a 360° live broadcast to a distant server.

Figure 3b compares the latency for STP and RTMP PULL modes when the stream is encoded at 15 Mb/s, which is higher than the stream encoded at 6 Mb/s. The camera is mounted at the SRT server in the second scenario so that a client can acquire the live feed and then send it to WebRTC for conversion. Figure 3c shows the comparison at 30Mb/s, which shows an increase in the end-to-end latency for all streaming protocols due to the network delay at a high bitrate. We evaluated the RTSP protocol's 360° stream delivery last.

The simulation results indicate that 360° 4K live streams may be transmitted with the least amount of end-to-end delay, providing the remote piloting supervisor enough time to direct the autonomous vehicles and make decisions.

Deployment Challenges and Solutions for Integrating 6G in Metaverse Ecosystem

This section presents the deployment challenges, open issues, and proposed solutions for the integration of 6G in metaverse applications.

Deployment Challenges

Security threats in wireless communication: Major technological advancements toward 6G will result in some security vulnerabilities in wireless communications. There are various security threats identified in such intelligent connected networks. For example, network automation may introduce potential threats such as deception attacks, man-in-the-middle (MIMT), and denial of service (DoS) attacks. Even eavesdropping, jamming, cursor jacking, and blind spot attacks may cause potential threats in connected vehicles and space-air-sea networks.

Solution: 6G networks should be designed with a robust security system to provide a secure communication system in the metaverse. Advanced cryptographic algorithms such as pre-post cryptography, elliptic curve cryptography (ECC), and quantum cryptography can be used to mitigate various security threats.

Metrics	5G	Beyond 5G	6G
Peak transmission rate	20 Gb/s	~ 100 Gb/s	+100 Gb/s–1 Tb/s
User experience rate	< 1 Gb/s	1 Gb/s	10–100 Gb/s
E2E latency (milliseconds)	10	1	< 1
Processing delay(ns)	100	50	10
Maximum bandwidth	1 GHz	20–50 GHz	100 GHz
Connection density	1M devices/ km2	<10M devices/km^2	10–100M devices/km^2
Mobility	500Km/h	~ 700km/h	1000km/h
Mobility	500Km/h	500Km/h	>700km/h
Reliability	99.999%	99.9999%	>99.99999%
Energy efficiency	1000x compared to 4G	100x compared to 4G	10x compared to 5G
Connected devices	Smartphones, sensors, drones	Smartphones, drones, sensors, XR equipment&	Smartphones, DLT devices, CRAS, XR and BCI equipment, smart implants, automated cars.
Computing technique	Cloud computing	Fog computing and cloud computing	Quantum computing, edge computing.
Security	Cryptographic algorithms	Key-based physical layer security	Quantum-safe cryptography, blockchain-assisted secure UAV communication, RIS-aided physical layer security.
Services	eMBB, mMTC, URLLC	Reliable eMBB, mMTC ,URLCC, hybrid (URLLC + eMBB)	MBBLLC, mURLLC, HCS,MPS.
Architecture	Massive MIMO	Massive MIMO	Ultra massive MIMO, intelligent surface.
Applications	Telemedicine, Internet of things, immersive gaming, virtual reality	360° video, UHD video, smart retail, smart grid, AR/VR	Internet of everything, 3D holographic (AR/VR), haptic communication, robotics ARM, BCI, tactile Internet, XR.
Haptic communication	Partial	Partial	Fully
Satellite integration	No	No	Fully
XR integration	Partial	Fully	Fully
Release year	2019 (South Korea)	2030 (expected)	2030 expected(China has launched a 6G test satellite)

TABLE 2. A comparison between 5G, beyond 5G and 6G.

Moreover, secure authentication protocols such as Kerberos, transport layer security (TLS), and public key infrastructure (PKI) can be used to ensure secure communication. Additionally, the deployment of blockchain technology will assure data protection, enhance network intelligence in big data processing, and ensure the security of IoT and XR networks.

TeraHertz (THz) band frequency: The frequency band of THz communications will support terabit per second data rates, extensive connectivity, secure transmissions, ultra-low latency, and higher spectral efficiency to fulfil the requirements of 6G applications. However, THz communications is a vital technology for the 6G and beyond network despite certain limitations, including substantial propagation loss, high reflection, rapid channel fluctuations, and constrained long-range communication.

Solution: Power amplifiers and VHF transceivers must be designed to support multi-GHz bandwidth. Inter-band inference must be properly modeled, examined, and suppressed in a multi-band system in order to fully utilize the bandwidth and fulfil the QoS requirements. The multi-hop relaying technique could extend the transmission range of THz communications and compensate for the high reflection losses.

TeraHertz (THz) beamforming: Beamforming supports high-data-rate communications with Massive MIMO. However, because of the propagation and penetration losses in the THz band, beamforming for sub-mm-wave communication is challenging. Further, hybrid beamforming architectures (HBAs) are also developed to achieve high spectrum efficiency and energy efficiency. But, deploying such HBAs in THzCom systems is difficult due to poor multiplexing gain, low efficiency, and channel squint effects.

Solution: A potential solution to address this challenge is to deploy distributed hybrid beamforming architectures (DHBAs) for THz communication systems. DHBAs can improve multiplexing gain, efficiency, and channel squint effects. Furthermore, deep learning-based channel estimation and tracking techniques can be used to improve THz beamforming accuracy.

High energy consumption: The 6G era will witness the widespread use of low-power devices, sensors, and battery-free smartphones to realize IoT. A significant amount of energy will also be consumed to power ultra-large-scale antennas for wide-band signal processing, tracking of mobile devices, and for ensuring adequate coverage for devices with ultra-narrow beams. Therefore, energy consumption will significantly hinder the success of 6G thereby requiring, the implementation of optimal energy-efficient technologies.

Solution: Metaverse needs a significant amount of energy due to continuous sensing and data transmission in 6G. The use of advanced energy-efficient techniques such as advanced antenna techniques, dynamic frequency, power management, and low-power transceivers will play a key role in reducing the energy consumption of 6G networks. The use of intelligent energy har-

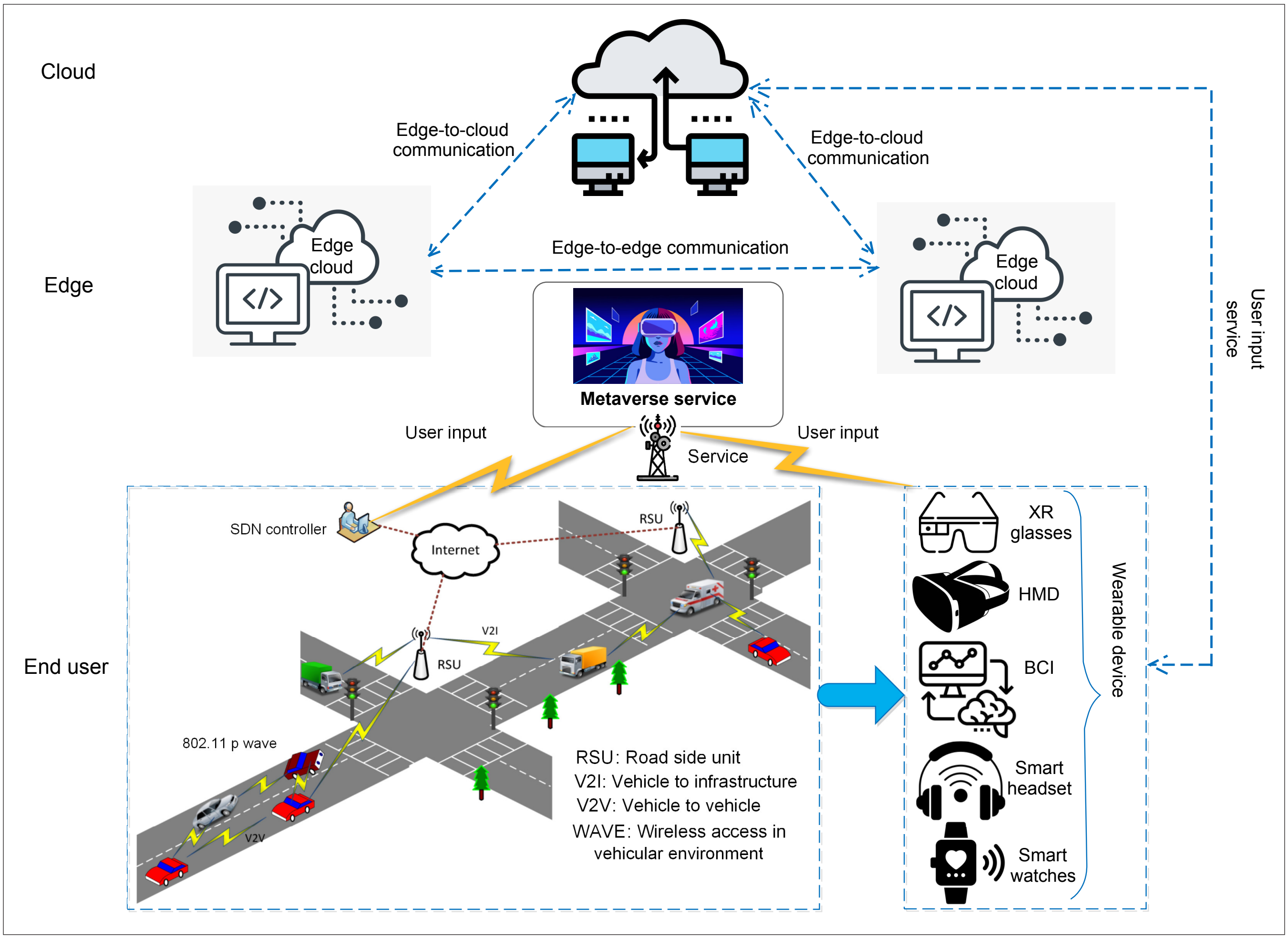

FIGURE 4. Metaverse in intelligent transportation system.

vesting, and wireless energy transfer techniques will also help in further reducing overall energy consumption. Furthermore, the use of edge computing and cloud computing to offload the workload from the base station will also help to reduce energy consumption.

Device connectivity and interoperability: The 6G network is expected to provide a wide range of additional functions, all of which the other devices need to support. It is very challenging to accommodate Tb/s data rates, AI, XR, and integrated sensing with communication functions using separate devices. Therefore, there is a crucial problem of device compatibility as we switch to and from diverse technologies.

Solution: In the 6G era, we must deal with the increased complexity of the metaverse, which will include a large number of heterogeneous devices and networks. To address this issue, we must develop cross-domain interoperability solutions which allow devices and networks to communicate with each other regardless of their underlying platforms or protocols. The deployment of 6G should be supported by the development of a standardized platform, such as the Metaverse Ecosystem, that will enable various types of devices to communicate with each other.

Inefficient resource utilization and latency: The immersive experience provided by the metaverse through AR/VR places significant demands on the mobile edge network infrastructure in terms of data rate, reliability, and latency. For the 6G network, ultra-low latency is a key requirement for a variety of applications (e.g., CRAS, XR, BCI). Maintaining a trade-off between rate, reliability, and latency is a concern in the development of ultra-low latency support architectures for spectral and energy efficiency provisioning.

Solution: Machine learning and deep learning solutions can assist in predicting user requests and changes in the state of the channel to reduce transmission latency. Network slicing can be used to provide low-latency communication, mobility, and resource management to improve end-to-end performance.

Co-channel interference co-ordinations: Co-channel interference between satellites and terrestrial communication networks caused by spectrum sharing is one of the main issues for ultra-dense B5G/6G networks. For instance, long-range communication and processing power constraints in satellite communications can cause channel state information (CSI) feedback issues. As a result, an appropriate approach for interference management must be created for extremely dense networks.

Solution: The probability density function or cumulative design can be utilized in future ultra-dense 6G wireless networks to prevent co-channel interference. To further improve the system's performance, a multi-objective evolution technique can be applied to address the interference problem.

Proposed Model for Metaverse in Intelligent Transportation Systems (ITS)

We describe our proposed system model for metaverse in an intelligent transportation system (ITS). We discuss the core aspects in detail, including the vehicular network, XR for connected vehicles, and cloud-edge-end orchestrations. Figure 4 illustrated the scenario of the metaverse in ITS, which focuses on three core layers. The cloud layer manages the computation and data maintenance at the cloud server. It is responsible for storing and managing the data and provides large-scale orchestration such as task scheduling and monitoring. The cloud network is connected to the edge, which is managed and deployed by a third-party infrastructure provider. The edge layer contains the edge servers that are co-located with RSUs, which compute, store, and transmit data closer to end users and their devices. Edge is connected to the end users who use their smart devices to interact with the metaverse.

The vehicular environment in an ITS provides an immersive metaverse experience powered by AR, AI, live streaming, edge computing, and V2X technologies. Dedicated short-range communication technology, which includes 802.11p, an improvement to 802.11 standards for wireless access in vehicular environments is used to provide high reliability, scalability, and mobility support. The metaverse in ITS, empowered by XR technologies, and wearable devices, including XR glasses, HMD, BCI, and smart headsets facilitates user/avatar interactions. Using various mounted devices, AR systems in XR technology will superimpose vehicle information such as speed, warning signs, and navigation on the windshield, enabling drivers to avoid obstacles in their path without being visually distracted. For example, if an unexpected pothole is encountered by the leading vehicle, then it alerts the preceding vehicles to prevent a potential accident. Even the vehicles in the congested areas broadcast to the entire network so that the vehicles might compute another efficient route. Thus, XR technologies may offer a potential method for increasing driver safety, thereby decreasing response time and increasing the possibility of hazard detection.

Conclusion

In this article, we presented a vision of the metaverse in 6G and beyond 6G wireless communications. We proposed a metaverse-based layered architecture for 6G to illustrate the digital and real-world relationship. We demonstrated a use case where we analyzed the performance of employing VR technology to provide remote assistance for autonomous vehicles in emergencies using end-to-end latency. Finally, we discussed the deployment challenges for integrating 6G in the metaverse, along with potential solutions.

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