6G to the Rescue: 6G Continuum for Metaverse Realization

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***Abstract*—The concept of metaverse aims to bring a fully-fledged extended reality environment to provide next-generation applications and services. Development of the metaverse is backed by many technologies, including, 5G, artificial intelligence, edge computing and extended reality. The advent of 6G is envisaged to mark a remarkable milestone in the development of the metaverse, facilitating near-zero-latency, a plethora of new services and upgraded real-world infrastructure. This paper presents the significant role anticipated for the 6th Generation (6G) mobile technologies towards realizing metaverse applications and services. Furthermore, it discusses prevailing challenges and relevant research directions towards ubiquitous and efficient metaverse applications and services in light of the capabilities of envisioned 6G networks.**

***Index Terms*—Metaverse, 6G, AI, Blockchain, Edge Computing**

I. Introduction

Metaverses have the potential to be transformative for business and society, nevertheless the widespread adoption of metaverse concept was previously hindered by network related issues such as high-latency, low-capacity, limited storage, insufficient security and end-user hardware problems such as heat generation, limited processing power and low battery life of small factor head-mounted devices. The time-critical communication capabilities in 5G make it possible to overcome only some of these challenges by offloading Extended Reality (XR) processing to the mobile network edge. Through evolving the already existing 5G networks, mobile operators are in an excellent position to enable the realization of metaverse on a large scale. This envisaged role for beyond-5G (B5G) mobile networks stems from the novel enablers under discussion in the research and industrial communities.

Commercial 5G mobile networks have been standardized and deployed globally, with significant coverage in some countries. New applications and use-cases are being developed, placing existing networks' capabilities to the test. The capacity of current 5G networks to handle the Internet of Everything (IoE), holographic telepresence, collaborative robotics, deep-sea and space tourism is limited [1]. This has prompted researchers to reconsider and work toward the development of the next generation of mobile communications networks called sixth-generation of mobile networks (6G) with substantially improved performance over 5G.

Researchers from around the globe propose artificial intelligence/machine learning (AI/ML), quantum communication/quantum machine learning (QML), blockchain, terahertz and millimetre wave communication, tactile Internet, non-orthogonal multiple access (NOMA), small cell communication, fog/edge computing, etc. as the key technologies for the realisation of 6G communications. The 6G aims to achieve high spectrum and energy efficiency, low latency, and massive connection due to the exponential growth of Internet of Things (IoT) devices. 6G will also effectively link the physical, digital worlds by providing seamless and ubiquitous services such as extreme-scale environmental monitoring and control, virtual reality/virtual navigation, telemedicine, digital sensing and robotics. This will result in a network that connects us to one another, to information, to knowledge, and to purpose. As a result, 6G networks will enhance the efficiency of technologies such as computer vision, blockchain, artificial intelligence, Internet of Things, robotics, and user interfaces which are critical for metaverse realization.

In summary, 6G will enhance every feature of the 5G network that benefits the user to improve areas such as smart cities, farming, manufacturing, and robots. 6G will provide enhanced productivity, capabilities, and better user experiences.

TABLE I
THE MAIN FEATURES OF 5G AND 6G COMPARED

Features	5G	6G
Data Rate	1 Gbps to 20 Gbps.	1 Tbps.
Application Types	Enhanced Mobile Broadband. Ultra-Reliable Low Latency Communications.Massive Machine Type Communications.	Massive Broadband Reliable Low. Latency Communication. Massive-URLLC. Human-Centric Services.Multi-Purpose Services.
Device Types	Smartphones, Drones, and Sensors.	Sensors & DLT devices,BCI and XR equipment, CRAS, and Smart implants.
Frequency Band	Sub 6 GHz and mm wave for fixed access.	Sub 6 GHz mm wave for mobile access exploration of THz bands. Non-RF bands.
Latency	5 ms	$<$1 ms
Architecture	Dense sub 6 GHz smaller BSs with umbrella macro BSs. Mmwave small cells of about 100 meters. Cell free smart surfaces at high frequencies.	Cell free smart surfaces at high frequencies. Temporary hotspots provided by drone-mounted BSs. Trials of tiny THz cells.
Spectral and Energy Efficiency Gain	10 x in bps/Hz/m^2.	1000 x in bps/Hz/m^2.
Traffic Capacity	10 Mbps/m^2.	1 to 10 Gbps/m^2.
Reliability	10^{-5}.	10^{-9}.
Localization Precision	10cm.	1cm in 3D.
User Experience	50 Mbps.	10 Gbps.
Mobility	500 km/h	1000 km/h
Connection density	10^6 devices/km^2	10^7 devices/km^2

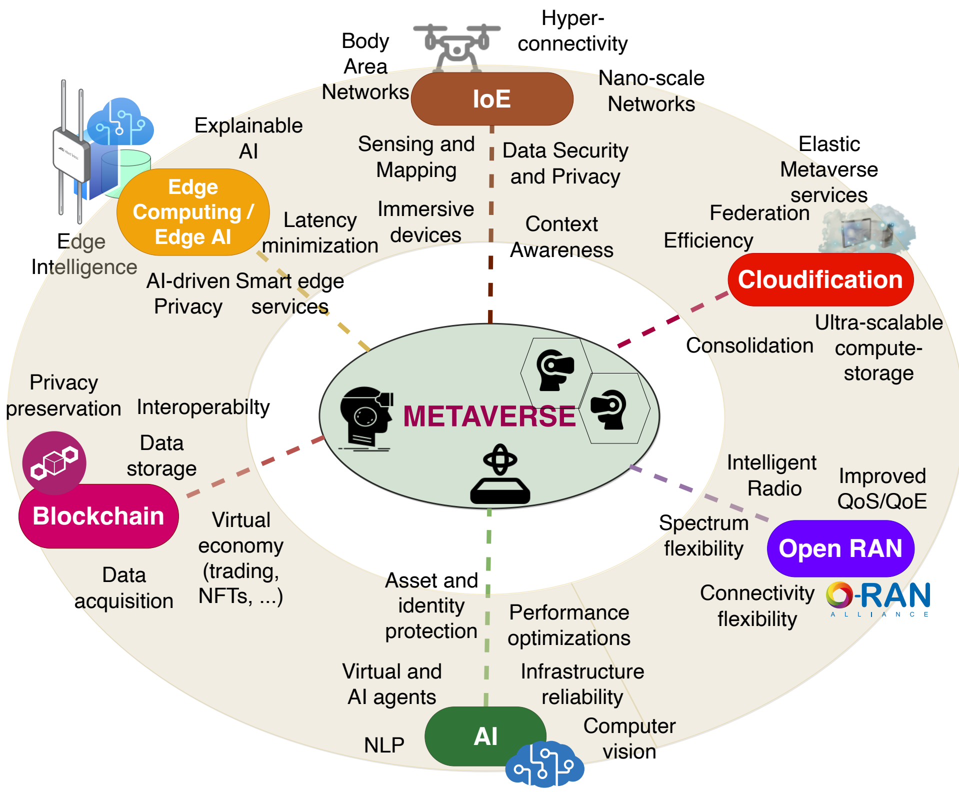

Fig. 1. Key 5G/6G technologies and their roles for the metaverse.

Improved and expanded functionality is an inevitability over successive generations. Even with 6G, this will be the case. 6G will improve upon 5G by optimising and lowering costs to increase adoption. The touchscreen interface of the future will instead be controlled by voice instructions, gestures, or even brain signals. The comparison of features related to 5G and 6G is depicted in the Table I.

The metaverse is a network of three-dimensional virtual environments dedicated to social interaction, which will be made possible by the usage of virtual and augmented reality devices [2]. The immersive experience of the metaverse will be enabled by cutting-edge technologies such as blockchain, augmented and extended reality, artificial intelligence and the Internet of Things. The metaverse will have a huge impact on applications such as healthcare (by linking patients to doctors and enhance doctors ability to provide consistent and customised patient care), real estate (by allowing organisations to establish retail and experience centres on its virtual land), manufacturing (by creating digital factories to assist in organising production and effective usage of machinery, for example firms can use virtual production systems to train new employees and staff on how to use them in the real world), tourism (by allowing hotel chains or travel agencies to advertise their services), Entertainment (by allowing users to attend virtual concerts and sporting events from first-row seats), and shopping (by selling products which customers can see, feel and touch with the use of sensors).

The main motivation of this paper is to investigate and delineate if mobile network operators can enable large-scale XR and at the same time further development of metaverses by introducing time-critical communication capabilities in 6G networks. Accordingly, we aim to establish the main advantages of providing metaverse services over 6G and provide an overview of the technical requirements. Furthermore, we aim to establish what role will a 6G play in a metaverse operation and if the envisaged architecture of 6G will be capable of supporting the upcoming technology portrayed by the tech industry.

II. Role of 6G Technologies for the Metaverse

The 6G will play a key role in metaverse operation since such an environment requires pervasive connectivity for full-fledged and omnipresent metaverse immersion. An important factor on this performance is the smart management of connectivity resources/services, scalable infrastructure and very low latency communications. Therefore, Edge AI and cloud infrastructure are necessary for efficient handling of relevant use cases in metaverse. Edge AI is an important enabler since it facilitates AI-driven optimized network management and mininimizes delay with distributed and close-to-the-user computing paradigm. This technology will be compounded with the AI native design of 6G which will be embedded for numerous functions ranging from physical layer control to service management. Furthermore, the required flexibility and scalability for network and service environment requires moving towards cloud-native technologies which can form telecommunication clouds for more efficient and scalable metaverse infrastructure in the backend. In the cyber-physical domain, the high-precision location ability, accurate mapping and real-time sensing will allow for the development of IoE scenarios and further improve robotics including sea/ground/air drones. Additionally, 6G will have the essential toolbox to enable AR/VR, which is critical since metaverse will be the main vessel for AR/VR experience. Appropriate immersive experience in metaverse will be possible with those technologies enabled by 6G communication and computation functions. As a transversal technology similar to AI, blockchain can also help the distributed and open nature of metaverse and enable the transferability of digital assets which will be an important capability for metaverse use cases. A depiction of these technologies and their roles is provided in Fig. 1.

III. 6G Capabilities and Its Role Towards the Metaverse Realization

This section investigates the capabilities provided by 6G and how those can function for the metaverse from the technical perspectives including cross platform integration, efficient support of AI, high speed data connection, content creation and storage, user interactivity, low latency communication, computer vision and privacy/security. The 6G capabilities and open challenges to overcome in order to enable envisaged metaverse functionalities are summarised in Figure 2.

A. 6G for Cross Platform Integration/Interoperability in the Metaverse

One of the hurdles in realizing the full potential of the metaverse is lack of interoperability [3], [4]. The metaverse should mimic the interoperability that is experienced in the physical world. For instance, in real/physical world we can take physical assets/objects from one place to another easily. The users in a metaverse too should be able to navigate seamlessly and freely to other metaverses. This is possible through interoperability that can form a glabally interconnected metaverse where various metaverses are integrated across the platforms as experienced in the real world. There is a need for a common, reliable network platform among multiple metaverses for seamless communication to enhance interoperability.

Realization of interoperability in the metaverse is a significant challenge as heavy objects such as digital avatars, 3D holograms etc. have to be navigated across in feature rich metaverse in near real time. It requires a communication infrastructure with high bandwidth and low latency. 6G network with its high bandwidth and ultra reliable low latency communication infrastructure can solve the issue of seamless communication in the metaverse. Network slicing, software-defined networking, symbiotic radio, and network function virtualization are the 6G techniques that promote network interoperability and agility in metaverse. Intelligent collaboration between diverse wireless signals is supported by symbiotic radio. The SDN/NFV offers open interfaces that facilitate interoperability between several metaverses and assist produce network slices for any vertical application such as gaming and shopping over the common physical infrastructure among different metaverses.

B. 6G for Efficient Support of AI in the Metaverse

Metaverse is a virtual world where the users will play games, interact with each others and the 3D objects in the virtual world, and build things in the virtual world. VR and AR along with blockchain and AI are the key enabling technologies in realizing the metaverse. The applications of AI in the metaverse include speech processing, content analysis, computer vision, etc. These applications of AI can be used to help build important components of the metaverse as discussed below:

Avatars: Avatars is one of the important and interesting concepts of the metaverse, where people in the physical world will create a digital avatar in the virtual world. People would like to get creative in the virtual world and they would like to see themselves in a different way which may not be possible in the physical world. AI plays a major role in the users designing their own avatars in the virtual world. AI can be used to analyze 3D scans or the user images to create accurate, realistic, and innovative avatars.

Digital Humans: In the metaverse, 3D chatbots are termed as digital humans. Digital humans respond and react to the actions of humans in the virtual world. They are usually non-playing characters that can be a character in a game of virtual reality whose actions and responses are dependant on a set of rules or automated script. They try to understand what the users are communicating by listening and observing them. Human-like interactions and conversations can happen in the metaverse between the humans and digital humans through body language and speech recognition. AI plays a significant role in the successful implementation of digital humans in the metaverse. Some of the key functionalities of digital humans like speech recognition, body language identification, object detection, etc. can be realized through AI.

Language Processing: In the metaverse the users can communicate and interact easily without the language barriers. AI can break the human language such as English into a format that can be read by the machines. The AI can then analyze the input, and provide a response back to the users in their language. The metaverse devices will fulfil the key requirements of building fully immersive virtual worlds, but they rely highly on local edge servers or far-off cloud data centres for processing the data, which is computationally intensive. Effective connectivity between servers and metaverse devices will thus be essential. The use of Edge AI can help applications and metaverse devices address these issues. Edge AI is the combination of edge computing and AI to run machine learning tasks directly on connected edge devices. Edge AI computes and processes data locally, which helps metaverse devices to be efficient and responsive in their communication. In the metaverse, huge volumes of heterogeneous big data will be generated at a very fast rate. 6G, with its characteristics such as fast communication infrastructure, near real-time processing, can help in processing/analyzing this big data to uncover the patterns existing in the data that trains the AI/ML algorithms in near real-time to make quick decisions/predictions through which several components of the metaverse can communicate easily.

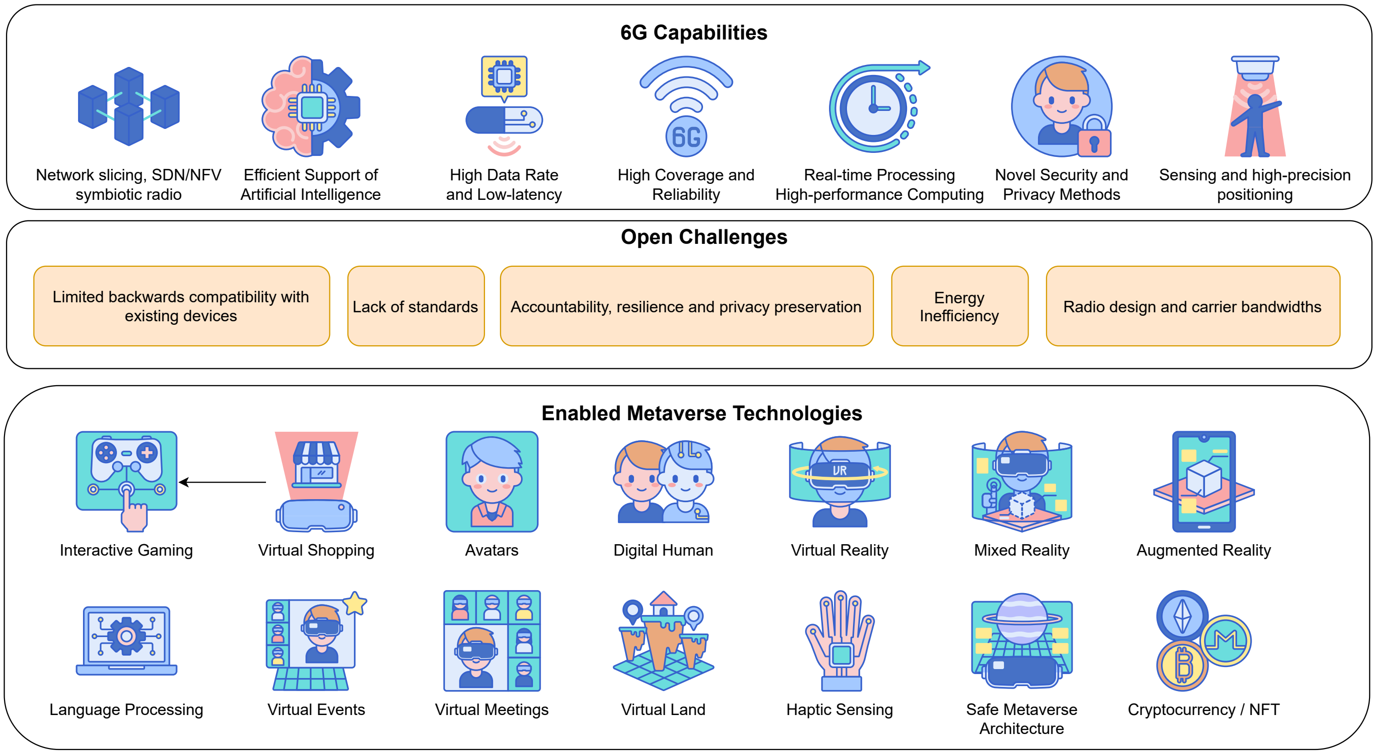

Fig. 2. 6G capabilities and open challenges that need to be solved to enable the underlying technology required to deploy fully functional metaverses

C. 6G for High Speed Data Connection in the Metaverse

The wide adaption of XR technologies is the key to the transition to the metaverse. It is expected that data usage to be increased by 20 times to what is being used today due to the revolution of the metaverse by 2022. To realize the full potential of the metaverse with real-time experience of AR and VR technologies, truly immersive 3D experiences. The end-users should be able to access high-speed data connections that can deliver the data at speeds of approximately 1 Gbps [5]. Some of the key requirements that will be needed to realize the true potential of metaverse are as follows:

- To create virtual reality worlds in the real-time, high speed data connection is required.
- The communication infrastructure should high speed transmission in near real-time with very low latency, typically, below 10 milli-seconds.
- The existing 4K video resolution may not be sufficient to convey the pixels for creating immersive worlds. Higher resolution videos have to be supported by the data carriers.
- Next generation video compression techniques that have the capability to compress and decompress huge data files in the metaverse in real-time are the need of the hour.

The key features of 6G with high-bandwidth and ultra-reliable and low latency communications [6] promise is a key enabling technology to realize the high bandwidth requirement of the metaverse.

D. 6G for Efficient User Interaction in the Metaverse

The metaverse enables the interaction between real-world entities and virtual objects. It is a digital environment that incorporates social networking, real estate, online gaming, AR, VR, and cryptocurrencies. In the metaverse, with the help of virtual objects, sounds, and other sensory inputs, AR tries to enhance the user's perception of the real world. Each time a user enters the metaverse, the objects around them undergo a dynamic transformation based on the requirements. Everything in the metaverse is constantly changing, which indicates the dynamic nature of the metaverse. Changes to a physical object are mirrored in its virtual counterpart in the metaverse because of their digital twins, which are linked to real-world objects. People can also change objects by interacting with them. Instead of just looking at digital objects in the metaverse, users will be able to experience a place and interact with them. The creation of new objects will require complex inputs and will demand high-quality user interaction with the objects in the metaverse. The metaverse poses three crucial challenges for effective user interaction:

Interacting with existing objects: Users physical interactions with these virtual worlds are an important consideration. When the user is unable to control the interaction, they will stop using it immediately. When a user is completely immersed in a virtual world and finds themselves unable to perform a task that they could do in the real world, they become frustrated and annoyed.

Modifying existing objects: As technology gets better and the real world keeps changing, the metaverse objects will need to be changed to make them seem more realistic. Realistic objects need more precise modelling algorithms, just like realistic faces. Even in the metaverse, where scenes and avatars are always changing and interacting, objects have to be changed all the time to reach this level of realism.

Creation of new virtual objects: The metaverse is a virtual 3D universe comprised of virtual 3D objects. The metaverse requires the creation of immersive experiences based on real-world artefacts in order to accomplish its objective of combining the digital and physical worlds. In the metaverse, a lot of digital objects will need constant sensor inputs from their physical counterparts to produce this realistic immersive experience for the users. As a result, it creates a huge requirement for bandwidth, which is a challenge to achieve with the present technology. Therefore, 6G is needed to provide ultra-reliable and low-latency communication and real-time processing abilities to aid in the building of a highly immersive 3D environment in the metaverse.

E. 6G for Low Latency Communication in the Metaverse

Low latency communication is the capability of the communication network to deliver large quantities of data with minimal delay and high accuracy. Advanced technologies like self-driving cars, holographic telepresence, remote surgery, deep-sea and space tourism, and other AR and VR innovations are becoming part of the metaverse. Future developments in VR and AR are well on their way to making an office where people can talk to each other in a fully immersive way. This integration of advanced technologies into the metaverse creates a huge demand for next-generation networks with enhanced bandwidth and latency. The capacity of current 5G networks to handle the IoE, holographic telepresence, collaborative robotics, and deep-sea and space tourism is limited. These applications require multiple terabytes of bandwidth as they depend on real-time inputs from the real world. Therefore, it is clear that the metaverse necessitates the highest network positioning accuracy and multiple terabytes of bandwidth. The 6G network, with its advancements like greater use of the distributed radio access network (RAN) and the terahertz spectrum to increase capacity and improve spectrum sharing, will provide effective and low-latency communication required for the metaverse [7].

F. 6G for Computer Vision in the Metaverse

Computer vision is the study of how computers perceive and interpret digital images and videos. Using sensors, computers, and machine learning algorithms, this multidisciplinary field replicates and automates essential parts of human vision systems. The objective behind computer vision is developing artificial intelligence systems that can see and understand their surroundings. Through the use of digital avatars and VR it provides a near-to-lifelike experience in the metaverse. In order to connect to this virtual world, the user needs to use XR devices, which are built on the foundation of computer vision. Visual information in the form of digital images or videos is often processed, analyzed, and interpreted with the help of computer vision and visual information. As a result of computer vision, VR and AR environments can be built that are more accurate, trustworthy, and user-friendly than their real-world counterparts. In the metaverse, the healthcare, military, construction, manufacturing, education, and retail sectors will rely largely on computer vision. Computer vision in the metaverse will evolve at an accelerated rate and 5G cannot compete with the rapidly evolving technological requirements of the metaverse's computer vision capabilities. The computer vision requires continual collaboration of heterogeneous devices in order to provide immersive experiences for the users, which requires uninterrupted network service, and should provide symmetric uploading and downloading speeds for users to quickly upload all their own content while concurrently downloading the content of others. 6G supports a higher number of device connections, which is very crucial for computer vision in the metaverse for delivering its fully immersive services to customers [8]. The independent frequency, higher data transmission rates, and large coverage of 6G will enhance the QoS of computer vision in the metaverse.

G. 6G for High Transaction Integration/Scalability

To date, metaverse implementations used centralized cloud-based approach for avatar physics emulation and graphical rendering. The centralized design is unfavorable as it suffers from several drawbacks caused by the long latency required for cloud access. Further deployments of metaverses will also bring scalability issues to the physical layer due to increased number of computing tasks mainly generated by extremely demanding applications. The traditionally deployed centralized architectures are unlikely to support large number of metaverses and their users, so the introduction of de-centralized metaverse systems including frameworks and protocols is inevitable. For example [9] proposed the blockchain-based MEC architecture, where base stations allocate their computation and communication resources for providing video streaming and the use of a series of smart contracts enables a self-organized video transcoding and delivery service without a centralized controller. Using the MEC more efficiently will not fulfil the requirements, so the decentralized architecture will have to further distribute the communication and computational cost among different nodes present in the virtual space. To overcome challenges related to high number of transactions, a massive resource demands and scalability concerns a novel framework should be proposed to address those emerging challenges for the development of future metaverses. To allow similar models, the 6G network needs to provide high data rates, low latency and almost real-time processing in order to handle multiple blockchains.

H. 6G for Security and Privacy Protection, eliminated criminal/hacker activities, Trust and accountability

Metaverses should offer their users an extraordinary immersive experience in virtual environments, such as entertainment games and smart cities, using its enabling technologies. The metaverse can track users' physical actions and physiological responses and may expose confidential information about their habits and physiological nature to third parties. If hackers get their hands on such sensitive information, it could lead to harassment and the theft of digital assets, which could make users lose faith in the security and privacy of the metaverse. These issues can be addressed by utilizing privacy-protection technologies like ”Private Copy” and ”Clone Cloud”. The creation of private copies and clone clouds is dependent on high connectivity and continuous integration with the metaverse environment. The edge intelligence facilitated by 6G can support the needs of these technologies in the metaverse. The use of a blockchain-based digital twin wireless network and an edge computing federated learning architecture can further enhance the users' privacy and data security [10]. Together with 6G, AI can optimize connectivity while also enabling traffic prediction and improving security in the metaverse. To avoid information breaches, physical layer communication may use a machine learning-based antenna design. Machine learning and quantum encryption can also be used to protect the security of communication devices in the metaverse. The metaverse's security may be increased by using early warning systems and AI-enabled 6G to identify network anomalies. The use of distributed and federated AI in a 6G network also eliminates the necessity for data sharing across the metaverse devices, which preserves the privacy of the users [11].

IV. Challenges and Research Directions

A. Limited backwards compatibility with existing devices

Effective communication in the metaverse requires compatibility with previous generation networks. Despite that some metaverse applications can operate on existing network capabilities devices due to the deployment of 6G these devices become worthless. A potential solution to address this issue is the backward compatibility of the 6G network with existing devices that enables the addition of high-capacity communication in the metaverse and also delivers faster data rates for applications requiring real-time processing and integration. The 6G networks should support the features of the previous generations of communications like 5G network for sometime, enabling progressive migration of the metaverse devices and lowering the overall cost of 6G and metaverse integration. In order to evaluate backward compatibility, mobile operators need to consider how the 5G and 6G core networks are connected and work on the 3GPP standard accordingly.

B. Lack of standards

There is a concern among users about the metaverse's potential legal consequences. If a problem arises, there is no agreed-upon policy framework or set of standards for integration of 6G with the metaverse. Any problem with the integration of these technologies will affect the trust and the capabilities of the 6G networks and the metaverse. These challenges may be resolved by establishing a forum involving service providers, researchers, and legal counsel to develop standards and policy frameworks that address concerns about user ethics, safety, and privacy while integrating 6G with the metaverse. The users should be provided with complete control and transparency of their data transmitted over 6G networks, which ensures their privacy in the metaverse. As a consequence, this will raise the bar for the 6G communication networks and the metaverse, which will increase trust among the users.

C. Accountability, resilience and privacy preservation

The functionalities across 6G integrated metaverse will be mostly automated based on the decisions made by AI. Any misclassification made by these decisions that cannot be traced because of the black box nature of AI will have a direct effect on the accountability of 6G integrated metaverse. Explainable AI (XAI) is a promising solution for this issue which allows to understand the misclassification issues and improve trust on the decisions made in 6G integrated metaverse. The usage of xAI will aid in pinpointing the problem's cause, assist the metaverse's administrators in understanding the issue, and motivate them to prevent a recurrence - this enhances the transparency of auditing of issues related to the 6G integrated metaverse. Additionally, existing and newly proposed AI algorithms need to be analysed considering their accountability, resilience and privacy preservation capabilities within the context of future networks.

D. Energy Inefficiency

The integration of processing, communication, sensing, and control capabilities inside a 6G network enables a seamless transition between the virtual and physical worlds, consequently contributing to the realisation of the metaverse. To support the requirements of the metaverse, the cellular capacity should be increased on top of existing network infrastructure. This will require 6G to deploy more microscopic and even micro-cells in the network. This increases technological and network complexity and will further strain the energy efficiency and sustainability of the metaverse. The integration of AI with 6G will address the issues of energy efficiency and network complexity, opening the door to a sustainable metaverse ecosystem.

E. Radio design and carrier bandwidths

One of the main goals of 6G is to achieve Tb/s data rates, which requires large bandwidths (10-100 GHz spectrum for THz bands), which requires an aggregation of large number of carriers to create larger bandwidth. Designing radios that work at sub-THz bands presents a significant challenge to the industry and research due to the complexity of associated RF circuits. Finding the right balance in terms of transceiver efficiency, power generation, heat dissipation and cost is critical for successful adoption of radios to sub-THz bands.

V. Conclusion

This paper presents the role of 6G towards realizing metaverse applications and services. The paper presents the role of 6G technologies for the immersive, smart, scalable and secure realization of the metaverse. Furthermore, the paper presents how various 6G capabilities play a key role towards the realization of the metaverse, including the role of 6G for, cross platform integration, efficient support for AI, high speed data connectivity, efficient user interaction, low latency communication, computer vision, high transaction integration, and security and privacy protection. Consequently, the integration challenges of 6G with metaverse is elaborated while providing several research directions towards realizing the metaverse owing to the capabilities of future 6G networks.

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