# IoT in Metaverse

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***Abstract*—This paper explores the one of the up-and-coming Web 3.0's technologies, the Metaverse, and its goal of creating a completely immersive, highly spatiotemporal, self-sustaining virtual shared place for humans to play, work, and interact in. This paper will also explore the Internet of Things (IoT) concepts like augmented reality, smart environment, etc. that have a ubiquitous presence now. In light of these new concepts, IoT has transformed the world by enabling seamless connectivity between heterogeneous networks (HetNets). The ultimate goal of IoT is to bring plug-and-play technology that provides the end-user with simplicity of operation, remote access control, and configurability. In this paper, I will present a comprehensive study on both the Metaverse and IoT, and then I will further discuss how IoT plays apart in the Metaverse, and its present applications. Finally, I draw open research directions for building future IoT systems for the Metaverse.**

***Keywords—Metaverse, distributed virtual worlds, extended reality, artificial intelligence, blockchain, IoT, augmented reality, smart environment, connectivity, heterogeneous networks, and plug-and-play.***

## I. Introduction

Metaverse is a computer-generated world with a consistent value system and an autonomous economic system linked to the real world. It is named after the prefix 'meta,' which means transcendence, and the suffix 'verse,' which is shorthand for universe. The term "metaverse" is constantly growing, with numerous definitions including 3D virtual worlds [1], second life [2], and lifelogging [3]. The metaverse is widely recognized as a completely immersive, hyper spatiotemporal, and self-sustaining virtual shared place that combines the ternary physical, human, and digital worlds [4]. It is recognized as an emergent paradigm of the next generation Internet following the web and mobile revolutions [5], where users can live as digital natives and have a virtual life. In this paper, the metaverse is defined as a virtual world that combines physical and digital elements, made possible by the confluence of Internet and Web technologies, and Extended Reality (XR). Generally, the development of metaverse consist of three phases: (i) digital twins, (ii) digital natives, and lastly (iii) surreality, as seen in Fig. 1. The first phase creates a mirror world of large-scale, high-fidelity digital twins of individuals and things in virtual surroundings. Virtual activities and properties such as user emotion and movement are imitations of their physical counterparts during this phase, in which reality and virtuality are two parallel spaces. The second phase is primarily concerned with native content creation, in which digital natives represented by avatars can generate innovations and insights within digital worlds and such digital creations may only exist in virtual spaces. During this phase, the massively created contents in the digital worlds are equal to their physical counterparts, and the digital world has the ability to transform and innovate the physical world's production process, resulting in more intersections between these two worlds. Finally, in the last phase, the metaverse evolves and transforms into a persisting and self-sustaining surreality world that integrates reality. This phase will see the seamless integration of the physical and virtual worlds, with the virtual world having a broader scope than the actual world and more scenes and lifestyles that do not exist in reality being able to exist in virtual realms.

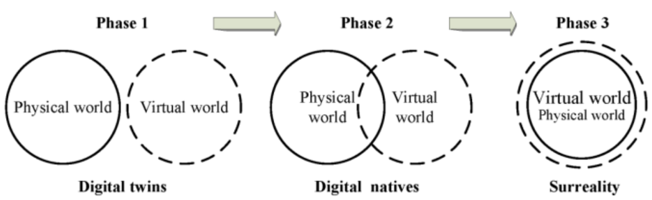


*Fig. 1 – Three phases of the development of the metaverse [6]*

Digital twins play an important part in integrating IoT with metaverse, because it plays a dual function in IoT: on the one hand, it is applied and recognized as a major strategy for developing IoT applications; on the other hand, it is naturally related with the capabilities of sensing and actuation of IoT technologies [7]. As a result, digital twin implementations have a close association with IoT capabilities. In addition, based on changeable data, digital twins can predict various outcomes. This is akin to the run-the-simulation scenario featured in science-fiction films, in which a conceivable scenario is demonstrated within a digital environment. Digital twins, when combined with additional software and data analytics, can frequently improve an IoT deployment for optimal efficiency, as well as assist designers in determining where things should go or how they should operate before they are physically installed.

The greater the ability of a digital twin to copy a physical object, the more likely it is that efficiency and other benefits will be discovered. For example, in manufacturing, when extensively instrumented devices are installed, digital twins could model how the devices have behaved through time, assisting in predicting future performance and potential failure.

## II. An Overview of Metaverse

This section introduces the metaverse from the following aspects: the general architecture, key characteristics, enabling technologies, and existing prototypes.

### A. *Metaverse Architecture*

The metaverse is a self-sustaining, hyper spatiotemporal, and 3D immersive virtual shared space created by the convergence of physically persistent virtual space and virtually enhanced physical reality, that is, the metaverse is a computer-generated universe made up of user-controlled avatars, digital objects, virtual settings, and other features, where humans, who are represented by avatars in the metaverse, can connect, collaborate, and socialize with each other using their virtual identities on any smart device. The physical, human, and digital worlds are all part of the metaverse's formation. Fig. 2 depicts the metaverse's overall

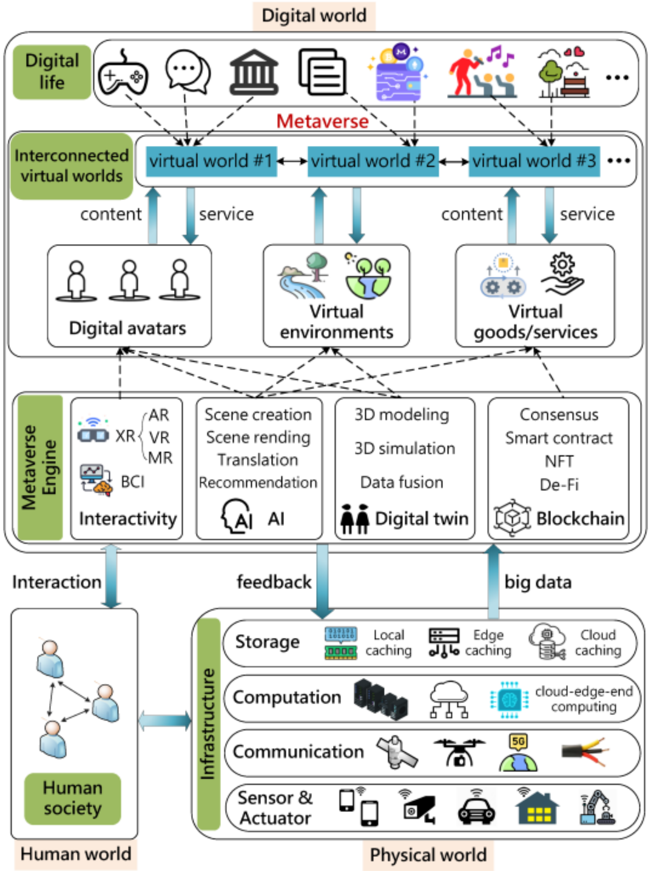


*Fig. 2 – The metaverse architecture [6]*

architecture while taking into account its underlying intricacies.

In conclusion, the social network connects the human world and is formed through common activities and mutual interactions among people. In the physical world, the IoT-enabled sensing/control infrastructure plays a critical role in reshaping the physical environment through pervasive sensors and actuators, and the resulting IoT big data is sent and processed via network and compute infrastructures. Lastly, in the digital world, the metaverse engine processes and manages the produced digital information of the physical and human worlds in order to facilitate large-scale metaverse development and numerous metaverse services. Furthermore, users (avatars) can create and distribute digital works across numerous sub-metaverses to foster the metaverse's creativity.

## B. *Key Characteristics of Metaverse*

Internet users are simply content consumers in web 1.0, consuming content provided by websites. Users in web 2.0 are both content producers and consumers, and websites are transforming into service delivery platforms. Such platforms include Wikipedia, Instagram, and TikTok. The metaverse has been identified as the web 3.0 development paradigm. Users are portrayed as digital avatars who can smoothly travel between various virtual worlds (i.e., sub-metaverses) to experience a digital existence and make digital products and economic exchanges, all while being supported by physical infrastructure and the metaverse engine.

*1) Immersiveness:* The computer-generated virtual space is realistic enough for users to be psychologically and emotionally immersed [8], which is also known as immersive realism. Human beings interact with their surroundings through their senses and body, according to the realism viewpoint. It can be approached via the structure of sensory perception (e.g., sight, sound, touch, and temperature) and expressiveness.

*2) Hyper Spatiotemporality:* The finite character of space and the irreversibility of time constrain the real world. Since the metaverse is a virtual space-time continuum parallel to the real one, hyper spatiotemporal refers to time and space limits being broken. As a result, users can freely travel between multiple worlds with varying spatiotemporal dimensions to experience an alternate existence with smooth scene transition.

*3) Interoperability:* It relates to the capability of users to move between virtual worlds (sub-metaverses) without losing their immersive experience, as well as the interchangeability of digital elements for rendering or reconstructing virtual environments across platforms.

*4) Scalability:* It refers to the metaverse's ability to remain efficient regardless of the number of concurrent users/avatars, the level of scene complexity, or the form of user/avatar interactions.

## C. *The Enabling Technologies of Metaverse*

There are six enabling technologies that which underlies the metaverse, as depicted in Fig. 3.

*1) Interactivity:* With the rising trend of miniaturized sensors, embedded technology, and XR technology, XR devices are anticipated to be the primary gateway to the metaverse [9]. These devices use holographic displays to deliver multimodal immersion, augmented experiences, and real-time user/avatar/environment interaction using virtual reality, augmented reality, and mixed reality technology.

*2) Networking:* Networking technologies such as 6G, IoT, and software-defined network (SDN) provide network access and real-time enormous data transmission across the real and virtual worlds in the metaverse, as well as sub-metaverses.

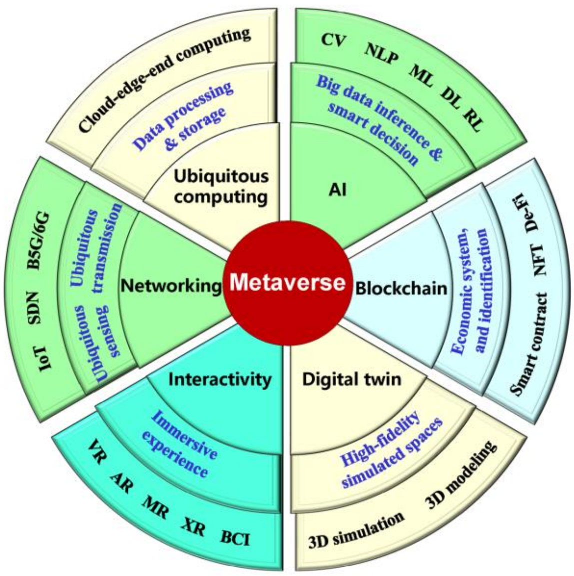


*Fig. 3 – Six underlying technologies of the Metaverse [6]*

*3) Ubiquitous computing:* It seeks to create an ecosystem in which computers are available to users at all times and in all places [10]. Pervasive smart items embedded in the environment or carried on the human body enable seamless adaptability to interactions between human users and physical surroundings. Instead of utilizing specific equipment such as a laptop, users can freely interact with their avatars and experience real-time immersive services via ubiquitous smart items and network access in the environment using ubiquitous computing.

*4) Digital Twin:* It portrays digital clones of real-world objects and systems with a high level of realism and sentience [11]. It permits the mirroring of physical entities as well as the prediction and optimization of their virtual bodies by assessing real-time streams of sensory data, physical models, and prior information. Data supplied back from physical entities in the digital twin can be utilised in the mirrored space for self-learning and self-adaptation.

### D. Exsisting Metaverse Applications

*1) Game:* Games are the primary distribution channel for metaverse apps. Games are a good method to explore the metaverse because to their technological maturity, user matching, and content versatility. Fortnite, Roblox, and Minecraft are a few examples.

*2) Social Experience:* The metaverse has the potential to transform our society by enabling a slew of immersive social applications such as virtual lifestyles, virtual dating, virtual talking, virtual purchasing, and even space/time travel.

*3) Simulation & Design:* Other interesting uses in the metaverse include 3D simulation, modelling, and architectural design. NVIDIA, for example, developed the Omniverse open platform to enable multi-user real-time 3D simulation and visualization of actual items and properties in a shared virtual environment for industrial applications.

*4) Online Collaboration:* The metaverse also gives new possibilities for immersive virtual cooperation, such as talking in virtual workplaces, studying and learning in virtual schools, and holding panel debates and meetings in virtual conference rooms.

## III. An Overview Of The Internet of Things (IoT)

This section briefly introduces IoT from the following aspects: the general architecture, enabling technologies, and existing applications.

### A. IoT Architecture

For the development of IoT, is divided into six layers as shown in Fig. 4.

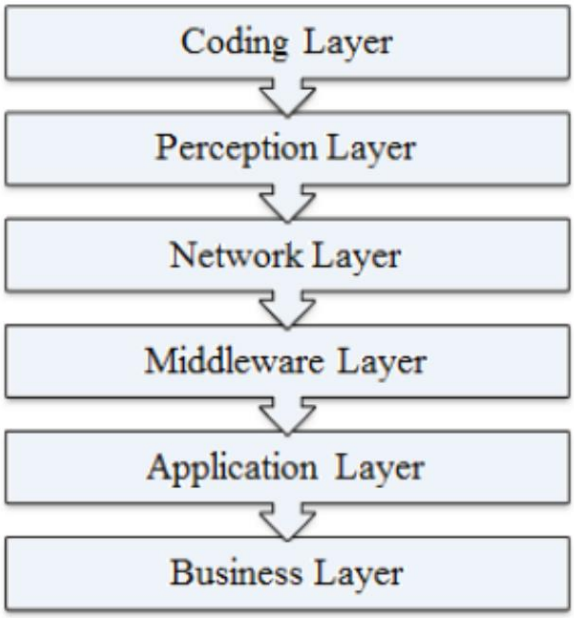


*Figure 4 – The six layers of the development of IoT [12]*

*1) Coding Layer:* The coding layer is the foundation of IoT, providing identification to objects of interest. Each object in this layer is given a unique ID, making it easy to distinguish between them [13].

*2) Perception Layer:* Each object has physical meaning thanks to the perception layer. It consists of data sensors in various forms such as Radio Frequency Identification (RFID) tags, Infrared (IR) sensors, and other sensor networks [14] that can sense the surrounding temperature, humidity, speed, and location of the objects, among other things. This layer collects useful information about objects from sensor devices and converts it into digital signals, which are then passed on to the Network Layer for further action.

*3) Network Layer:* The purpose of this layer is to receive useful information from the Perception Layer in the form of digital signals and transmit it to the processing systems in the Middleware Layer via transmission mediums such as WiFi, Bluetooth, ZigBee, GSM, 3G, and so on, using protocols such as IPv4, IPv6, MQTT, and so on [15].

*4) Middleware Layer:* This layer is responsible for processing the information received from the sensor devices [16]. It includes technologies such as cloud computing and ubiquitous computing, which provide direct access to the database and allow it to store all necessary information. The information is processed using Intelligent Processing Equipment, and a fully automated action is taken based on the processed results of the information.

*5) Application Layer:* Based on the processed data, this layer realizes IoT applications for all types of industries. This layer is useful in the large-scale development of the IoT network because applications promote the development of IoT [17].

*6) Business Layer:* This layer manages IoT applications and services and is in charge of all IoT-related research. It generates various business models that can be used to develop effective business strategies [18].

### B. The Enabling Technologies of IoT

The development of a ubiquitous computing system in which digital objects can be uniquely identified and can think and interact with other objects to collect data on which automated actions are taken necessitates the need for a combination of new and effective technologies, which is only possible through the integration of different technologies that allow the objects to be identified and communicate with one another [19]. This section discusses the technologies that can aid in the widespread development of IoT.

*1) Radio Frequency Identification (RFID):* RFID is the main technology for making objects uniquely recognizable. For its small size and low cost, it may be incorporated into any item [20]. It is a transmitter microchip, similar to an adhesive sticker, that can be active or inactive depending on the application [21]. RFID technology are classified into four frequency bands [22] based on the type of application:

*(1)* Low Frequency (135KHz or less)
*(2)* High Frequency (13.56MHz)
*(3)* Ultra-High Frequency (862MHz – 928MHz)
*(4)* Microwave Frequency (300GHz)

*2) Wireless Sensor Network (WSN):* WSN is a bi-directional, wirelessly connected, multi-hop, network of sensors built from several nodes scattered in a sensor field, each connected to one or more sensors that can collect the object's specific fata such as temperature, humidity, accelerometer, and so on and then pass on to the processing equipment. Multi-hop communication is used by the sensing nodes. Each sensor is a transceiver that includes an antenna, a microcontroller, and an interfacing circuit for the sensors to serve as a communication, actuation, and sensing unit, as well as a power supply such as a battery.

*3) Cloud Computing:* With millions of smart gadgets now on the market, the cloud appears to be the only technology capable of successfully analysing and storing all data. It is an intelligent computing system in which a number of servers are converged on a single cloud platform to allow resource sharing between them, which can be accessed at any time and from any location. Cloud computing is the most significant component of IoT, as it not only converges servers, but also processes on a higher processing power and analyses the useful information acquired from sensors, as well as providing adequate storage capacity.

*4) Networking Technologies:* These technologies are critical to the development of IoT since they are responsible for connecting items, thus we need a fast and efficient network to handle a high number of potential devices. We usually employ 3G and 4G networks for long-distance transmission networks, and Bluetooth, WiFi, and other short-distance communication networks.

*5) Micro-Electro-Mechanical Systems (MEMS):* MEMS are a combination of electric and mechanical components that work together to enable a variety of applications such as sensing and actuating that are already being utilized commercially in several sectors such as transducers and acceleromete s.

### *C. Exsisting IoT Applications*

Most of the applications we use in our daily lives are already intelligent, but they are unable to communicate with one another. Enabling them to communicate with one another and share relevant information will result in a wide range of creative applications. These new applications with self-driving capabilities would undoubtedly improve the quality of our lives. One example is any of the Tesla cars, which are part of an initiative to deliver self-driving car experiences with real-time traffic, road conditions, weather, and other information exchanges, all thanks to the Internet of Things concept. There are a lot of potential future applications that could be quite beneficial. Several of these applications are presented in this section.

*1) Smart Home:* IoT will enable DIY solutions for home automation, allowing us to remotely operate our appliances based on our needs. Proper monitoring of utility meters, electricity, and water supplies will aid in resource conservation and the detection of unexpected overloading or water leaks. Furthermore, gardening sensors will be able to assess light, humidity, temperature, wetness, and other gardening vitals, as well as water the plants as needed.

*2) Smart Environment:* Natural hazard prediction, such as earthquakes and floods, will be achievable because to IoT's revolutionary technology. The environment's air pollution will be properly monitored.

*3) Smart Agriculture:* It will monitor soil nutrition, light, humidity, and other factors, and will enhance the green house experience by automatically adjusting the temperature to optimal production rates. Water quality will improve and fertilizers will be saved if watering and fertilizing are done correctly.

*4) Smart Hospitals:* Hospitals will be equipped with smart flexible wearables embedded with RFID tags, which will be handed to patients upon arrival, allowing not only doctors but also nurses to monitor patients' heart rates and blood pressure both within and outside the hospital's premises.

## IV. INTERGRATING IOT WITH THE METAVERSE

IoT is critical to the Metaverse's network infrastructure. IoT sensing gives users with a truly authentic, long-lasting, and seamless interactive experience that connects the Metaverse with the real world. Metaverse apps are the result of the intelligent cloud and intelligent edge functioning in tandem—at their core are digital twins. We can develop sophisticated digital representations of anything physical or logical, from simple assets or goods to large environments, using digital twins. These environments can include energy distribution grids, warehouses, or factories—whatever is crucial to you. It can then be brought to life and synchronized with the physical world utilizing two-way IoT connections once it has been modelled. This initial connection of the physical and digital is required for metaverse apps to function. The extent of digital twins can be defined in two ways. According to one viewpoint, a digital twin is an umbrella term that encompasses data input, data management, modelling, and simulation. The alternative method is to serve as a mirror for a unique physical object and its digital reflection, which may be considered as modelling and simulation as applications that can be developed on top of a digital twin and its data exhaust or historical data. In recent years, the most accurate digital twin application which some may call the metaverse is a fitness tracker or smartwatch that can measure one's heart rate in a social fitness application. This section will present a few ideologies or products that integrates IoT with metaverse and I will write a comprehensive review for each example, along with its advantages and disadvantages.

*1) VR:* As VR is one of the enabling factors of metaverse, using physical devices which leverages IoT will supplement one's experiential interface into a virtual world or metaverse. One of the most common examples of combining IoT and VR nowadays is having IoT devices linked to one's body or a sensor-laden body suit to instrument the state of one's own condition and health, which may elicit a response in the virtual environment [20]. One application is the now-defunct Microsoft's Xbox Kinect. The Kinect uses motion controllers that translate gesture and skeletal detection into control signals for gaming, and one instance of using the motion sensors that translates into game is Just Dance. It is a rhythm game which is primarily played through motion controls. The player will mimic the dance moves that are reflected on the screen and the game will pick up the player's movements through the Kinect's camera, which thus will generate a three-dimensional (moving) image of the objects in its field of view, and recognize (moving) human beings among those objects [21]. The Kinect's success was the first few products that used IoT idealogies to be used in a VR, which is the metaverse. The success was due to the fact that when the Kinect was released, there were only a hnadful of products that had similar selling points and state-of-the-art technologies as the Kienct. However, one of the most common disadvantages is that the Kinect does not work well in an outdoor setting [22]. To counter this issue, Microsoft developed a newer Xbox One that is still popular in the market.

*2) AR:* Another enabling factor of the metaverse is AR. IoT acts as one's sensory network in the AR metaverse, bringing physical objects into the digital sphere. It gives AR apps context and situational awareness, as well as triggers for items in the digital and virtual realms to interact with things in the physical world. IoT provides that physical-to-cyber bridge, whether it is the spatial positioning of digital things in your field of view, an AR object reacting to one's finger gestures, or initiating a cyberphysical application or function based on an event occuring in the physical world [20]. One example of integrating IoT with AR is the popular AR game for smartphones, Pokémon Go [23]. Pokèmon Go is a gaming app that employs limited AR and geolocation. The game is a great illustration of how IoT and augmented reality have blended mobility into video games while also making players feel like they are a part of the game's plot. In this game, IoT allows one to go 'catch' Pokémons by synchronizing the software with one's smartphone's GPS, camera, and other sensors like the accelerometer. By pointing the camera towards the Pokémon, it will feel as though the player is 'catching' the Pokémon in real-life with the player's surroundings. Though it is still popular to this date, the major disadvantage of the app is that it may be difficult to use indoors because it requires an active internet connection and GPS to function, and playing the game indoors will result in a transient loss, which may possibly mess up the game [24].

*3) Dynamic Resource Allocation Framework for Synchronizing Metaverse with IoT Service and Data:* This paper [25] presents a comprehensive study on a group of IoT devices that are employed by the metaverse platform to collect data on behalf of Virtual Service Providers (VSPs). This study was done as the resource allocation problem for syncing Metaverse with the assistance of IoT sensing data has not received much attention, as the Metaverse is still in its nascent stage. According to the study, the authors took on two approaches – population game formulation and hybrid evolutionary dynamics. The authors presented hybrid evolutionary dynamics for a heterogeneous multi-population game, given a huge number of IoT devices, a hardly-achieved full rationale, and probable diverse in-population communication protocols. The equilibrium approach has been experimentally proven to exist and to be stable. In conclusion, as the metaverse concept is reletively new, this paper explained the research gap comprehensively. The notion behind the paper can be improved when there is a substantiate concept behind the metaverse in the future.

*4) Scalable Consensus over Finite Capacities in Multiagent IoT Ecosystems:* The authors of this paper [26] investigate the process of developing and sustaining scalable consensus policies over the trivial atomic capacities of IoT ecosystems, after discovering that in order for IoT ecosystems and the metaverse to become self-sustaining and self-evolving, robust validity mechanisms must be embedded at the atomic scale. The authors addressed this issue in this study by establishing transitive consistency rules that can efficiently guarantee universal validity and transactional trust in IoT ecosystems and the metaverse under conditions of high variety, eventual consistency, and limited atomic capacity. When given a low-level consistency layer that is resistant to computational attacks and lightweight enough, such as the IoT micro-Blockchain, each atom can become a distinct element of the system's reality. It can see and be witnessed by others in a peer-to-peer way, and have an overall favorable impact on the system's coherency. In conclusion, it was a well-defined review on IoT ecosystems and the metaverse to become self-sustaining and self-evolving.

## V. The Future of IoT systems in the Metaverse

Evidently, there are already existing products and ideologies that integrates IoT systems in the metaverse. It is expected that by 2025, the total IoT connected devices will reach 30.9 billion, with a sharp jump from the 13.8 billion in 2021 [27]. As a result, many observers believe that combining IoT and AR/VR/MR may be appropriate for multi-modal interaction systems in order to generate compelling user experiences, particularly for non-expert users. However, there are still bottlenecks, when IoT integrates with the metaverse. For example, consider the disparity between data explosion and restricted sensing resources. The solution of selective perception was proposed by F. Shi et al. [28]. Poor sensor/actuator performance is another constraint. To solve this issue, H. Ning et al. [28] stated that nanotechnology has the potential to increase sensor/actuator performance (e.g., higher sensitivity and selectivity, shorter response time, and longer service life). As a result, the use of nanomaterials (e.g., graphene, nanowires, etc.) will open up new possibilities in the field of Metaverse sensing and communication. Having said that, the demand for more advanced IoT systems will rise as a result of Metaverse and its immersive virtual environment. The real craze in the Metaverse, as some researchers may have stated, is in augmented reality. The ability to maintain connectivity between the virtual and physical worlds is crucial for boosting demand for IoT spending. As the metaverse blurs the border between reality and virtuality in the future owing to XR, it will need to rely on IoT devices such as sensors and wearables (sensor gloves, head-mounted devices, goggles, etc.). All things considered, it is certain that the metaverse will have a significant impact on the evolution of IoT. This is due to the fact that the metaverse will give a platform for people to interact with items in a realistic manner, paving the door for further innovation in the field of IoT. Furthermore, it will make it easier for users to produce and share content, which will encourage developer collaboration and help to accelerate advancement in the field of IoT.

## VI. Conclusion

The paper presents an extensive study of the metaverse, and its supporting applications, as well as a brief introduction to IoT. It also presents the integration between IoT devices and the metaverse and how they work in tandem with the metaverse by providing data to be inputted in the metaverse. In addition, the paper also explores the endless possibilities of creating new IoT devices in the near future to be used with/in the metaverse as the metaverse is still a relatively new concept in this day.

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