NEXT G ALLIANCE
An ATIS Initiative

Digital World Experiences

6G

Next G Alliance Report:

Digital World Experiences

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FOREWORD

As a leading technology and solutions development organization, the Alliance for Telecommunications Industry Solutions (ATIS) brings together the top global ICT companies to advance the industry's business priorities. ATIS' 150 member companies are currently working to address network reliability, 5G, robocall mitigation, smart cities, artificial intelligence (AI)-enabled networks, distributed ledger/blockchain technology, cybersecurity, IoT, emergency services, quality of service, billing support, operations and much more. These priorities follow a fast-track development lifecycle from design and innovation through standards, specifications, requirements, business use cases, software toolkits, open-source solutions, and interoperability testing.

ATIS is accredited by the American National Standards Institute (ANSI). ATIS is the North American Organizational Partner for the 3rd Generation Partnership Project (3GPP), a founding Partner of the oneM2M global initiative, a member of the International Telecommunication Union (ITU), as well as a member of the Inter-American Telecommunication Commission (CITEL).

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The ATIS Next G Alliance is an initiative to advance North American wireless technology leadership over the next decade through private-sector-led efforts. With a strong emphasis on technology commercialization, the work will encompass the full lifecycle of research and development, manufacturing, standardization, and market readiness.

EXECUTIVE SUMMARY

Digital World Experience (DWE) is a multi-dimensional, multi-party, and multi-sensory experience that transforms human interactions across physical, human, and digital worlds. The combination of these technologies is expected to yield human and machine experiences. This paper takes a closer look at the societal and economic opportunities that can be made possible through DWEs as well as 6G research and technology directions required to help realize DWEs.

The paper identifies several DWE use cases, such as immersive multi-sensory XR, network enabled robotics and autonomous systems, along with several technical challenges impeding their realization, e.g., lack of smaller form factor and lighter weight XR headsets/glasses. Also identified are several key 6G research and technology advancement areas that will enable DWEs, such as networks with interacting haptic sensors (tactile and kinesthetic), sub-msec latencies for instantaneous haptic feedback, and support for coordinating distributed computing across network nodes and devices.

Several developments and efforts across the industries involved will be needed for a path to realization:

- Ecosystem, standardization, and FOSS development
- Operating systems and platform innovations
- Technology accumulations and hardware innovations
- Innovations in rich content applications

The paper outlines these efforts spanning across several industries and stakeholders, including communications and computing providers, device manufacturers, policy makers, applications developers, and end users.

1 INTRODUCTION

Today, the majority of people globally are digitally connected. Trillions of dollars are being spent on digital transformation efforts across all industries. Breakthrough technologies related to Artificial Intelligence (AI), the Internet of Things (IoT), and cloud computing – amongst others – have the potential to redefine the possibilities for modern enterprises and our everyday life. To reach the full potential of these technologies and to get the most out of digital investments, the human experience cannot be ignored as behind every digital experience there is a human. Hence, the role of technology must be to serve humanity, societal needs, and evolution of our living environment or nature in general.

With advances in IoT, AI, cloud computing, robotics, and other technologies, 5G is the first generation of mobile networks designed for highly interactive collaboration amongst humans and 'smart things', be it machines, cyber-physical systems, or any combination of the above.

As the world develops more comprehensive technologies, the foundation of a strong 5G and beyond network is critical to usher in and to support emerging applications and optimized experiences in the above-mentioned digital world. This will be an instrumental consideration in defining the path toward 6G mobile networks.

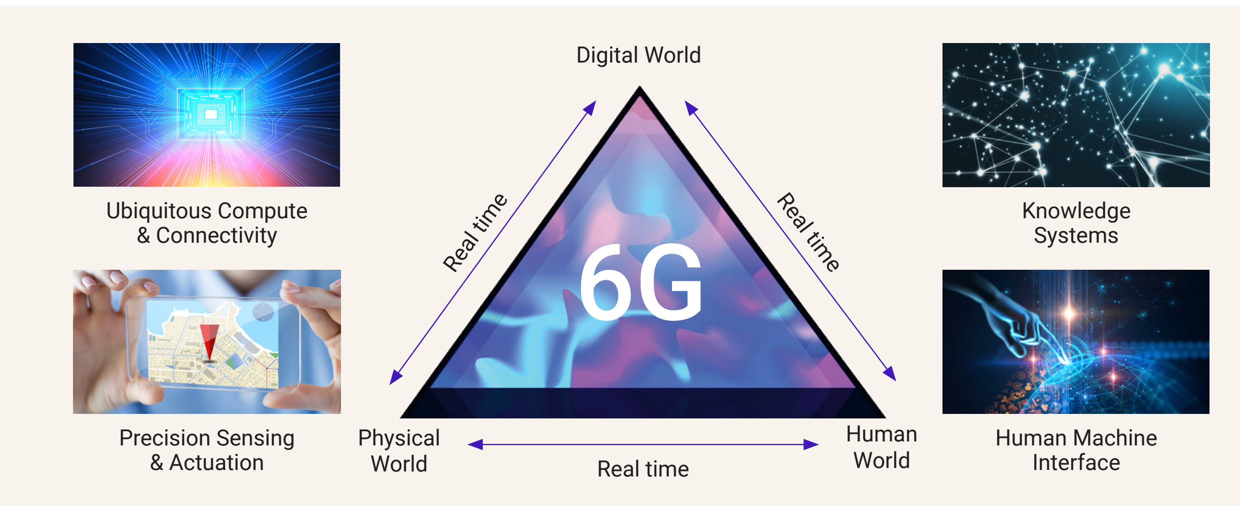


Figure 1 - Towards the merge of the physical, human, and digital world.

The sixth generation (6G) of mobile networks is already making headlines in the digital world and experiences therein. It is expected that future applications will rely on the merging of the digital and physical worlds to create a wide variety of highly immersive experiences through deeper levels of human-machine interactions. These immersive experiences will rely on 6G systems and complementary technologies, e.g., innovative sensing, immersive XR, distributed inferencing, management, and intelligence computing. The combination of these technologies is expected to yield human and machine experiences unthinkable with previous generations.

Digital World Experience (DWE) is a multi-dimensional, multi-party, and multi-sensory experience that transforms human interactions across physical, human, and digital worlds. Innovative human-machine interfaces, precision sensing and actuation, ubiquitous compute and connectivity, and the introduction of innovative knowledge systems are expected to be enablers of more expressive DWE interactions and immersive experiences.

DWE does not simply imply a digital transformation of the physical world, it merges the physical, human, and digital worlds as illustrated in Figure 1. This merger requires the sensing and actuation of objects, responses to human behaviors, and detection of environmental changes – all calling for questions such as "What are the driving forces for DWEs?", "Which research challenges do DWEs brings to realization?", "What are the key technology directions for DWEs?", and "Which path(s) should be defined and followed for enabling DWEs?" – these are the questions that are highlighted and discussed in this whitepaper.

DWE is cross-domain in nature and calls for the joint consideration of various technology domains. One of the key technical foundations for achieving DWE is the realization of distributed cloud and communications systems for 6G [1] [2]. Applications and use cases intrinsic to the DWE are envisioned to be thriving in an ecosystem enabled and nurtured by the flexibility, in terms of performance and scale, offered by services inherited through the 6G Distributed Cloud and Communications System.

To achieve perceived real-time experiences in audio, visual, and haptic interactions within the digital world, predictive, proactive and interactive, and intelligent solutions will be needed. Therefore, an AI-native infrastructure with solutions expanded through 6G networks will be essential.
While considering digital equity for all, one objective for DWE

services is to offer the service to anyone anywhere in the world with cost-efficient solutions with a common reusable infrastructure, cloud-native function deployment, automation, and lowering device costs.

One of the key aspects to be ensured in DWEs is trustworthiness, which is related to the safety, security, reliability, and resiliency of the systems providing services. Adequate safety measures to protect users, reliability, and resiliency of the hardware and software, as well as new security and privacy protections must be addressed right from the beginning in 6G systems design.

Finally, environmental and economic sustainability, which is another key challenge in DWEs, should be supported by flexible and efficient solutions in 6G systems.

2 DRIVING FORCES AND NORTH AMERICAN IMPERATIVES

2.1 Potential Societal Opportunities

The most significant societal opportunities that can be made possible through DWEs are in education and healthcare. Similar to how the Internet has democratized information sharing and communication, DWEs have the potential to do the same in various other use cases. Opportunities include augmented reality experiences to help learners parse complex visual information, more immersive and effective remote learning experiences, improved access to education, and the creation of novel techniques to model and manipulate our physical world. These outcomes are relevant to United Nations (UN) Sustainable Development Goal (SDG) #4, "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all".

Another major area of opportunity is healthcare. Telehealth has been a growing industry, with sudden and rapid adoption being forced by the COVID-19 pandemic. In contrast to traditional health experiences, the flexibility of telehealth can lead to improved accessibility, as patients with quick questions no longer need to take time off work or travel to receive medical advice. These all make progress on UN SDG #3, "Ensure healthy lives and promote well-being for all at all ages". Today's telehealth experiences are just the beginning, though. Opportunities for improvement may include the creation of technology that allows providers to "see through patients' eyes", and enabling broader access to experts through robotic surgery and other remote procedures. We anticipate that the primary challenges in this area will be in the safety and security of patients and patient data. In robotic surgery, for example, it may be prudent to invest in formal verification techniques to ensure disasters do not reoccur.

2.2 Potential Economic Opportunities

The following discussion will focus primarily on the economic impacts of two increasingly common phenomena where we anticipate DWE will have a significant role: remote work and automation. Remote work and automation both play a role in UN SDGs #8 and #9, "Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all" and "build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation."

Digital world experiences will enable employers to provide both more efficient remote work experiences, and more fulfilling remote work experiences for the enterprise. Remote work is increasingly in demand, and has a number of advantages: it leads to decreased emissions due to the elimination of commutes, it ensures greater geographic diversity in employees, and it has the potential to create more equitable access to high-quality employers [4]. DWEs have the potential to make remote work even more effective and rewarding through innovations like immersive collaboration. Despite high employee demand for remote work, most acknowledge that there still are disadvantages compared to in-person interactions. More study is needed on the impacts of long-term remote work on employee satisfaction, company productivity, and innovation.

The cyber-physical systems arm of DWEs presents interesting opportunities for automating tasks that are too dangerous or undesirable for human workers. For example, using robots and sensors to rapidly and efficiently sort recycling and remove contaminants [4], or to enable precision agriculture techniques to maximize food production while minimizing resource consumption. Both use cases are relevant to UN SDGs #12, #14, and #15. These opportunities must be balanced with the fact that automation is very threatening to some, with perceptions that it will lead to job loss. Fortunately, new jobs for developing the new services will be created, which means care needs to be taken to ensure that all socioeconomic levels can equally reap the benefits of automation. Societies and companies must also invest in continuous digital education so that employees can competently use new technology as it rapidly develops, thus preventing aging out of the workforce due to digital illiteracy.

2.3 Potential Use Cases and Application Trends

To date, the Next G Alliance has identified the following four categories of 6G use cases [5]: Network Enabled Robotics and Autonomous System, Multi-Sensory Extended Reality (XR), Distributed Sensing and Communications, Personalized User Experiences.

Each of these four use case categories have a strong relationship to DWEs and will contribute to the full-scale evolution of DWEs by incorporating societal needs, user expectations and requirements, emerging applications, and ongoing (technological) trends. In this context, 6G systems are expected to provide the underlying connectivity, networking, and other required functions and resources to i) achieve full autonomy, ii) offer multi-sensory capabilities for seamless interactions with real or virtual objects when physical and digital worlds merge, and iii) deliver personalized solutions and services to everyone anywhere in the world.

For each of these four use case categories, the Next G Alliance has identified several use cases and their corresponding 6G requirements having relevance to DWEs. These are summarized in the table below.

Categories	Use Case Examples Having Relevance to DWEs	Characteristics of Potential Requirements
Network Enabled Robotics and Autonomous Systems	> Online cooperative operation among a group of service robots. > Field robots for hazardous environments.	Synchronization precision, reliability, end-to-end latency, availability, privacy, security, trust, AI/ML support, closed-loop control.
Multi-sensory XR	> Ultra-realistic interactive sports (e.g., drone racing). > Immersive gaming and entertainment. > Co-design merged reality. > Mixed Reality (MR) telepresence and teleportation. > Immersive life (education, health care, retail, etc.)	End-to-end latency, jitter, experienced data rate, availability, edge/distributed/spatial computing, haptic codecs, human-computer-interaction enablement, devices, privacy, security, trust.
Distributed Sensing and Communications	> Public safety applications. > Remote-area data collection, a scenario that includes sensors tightly integrated with communications to support autonomous systems. > In-body networks for health care.	End-to-end latency, experienced data rate, availability, positioning accuracy
Personalized User Experiences	> Personalized hotel experiences such as real-time automated guest assistance, virtual hotel concierge, and automated room service. > Personalized shopping experiences such as immersive product demos, gamification of retail experiences.	End-to-end latency, experienced data rate, availability, privacy, security, trust, AI/ML support, haptic codecs.

2.4 Potential North American Impact

DWEs will benefit various applications and use cases (see 2.3) and have a significant impact on the population and economy of North America. Likewise, North America has the opportunity to take a significant leadership role in DWE research, technology development, innovation, and educating society about DWEs.

Two industries in North America that have great potential for gain by embracing 6G DWE technologies are the Entertainment Industry and Healthcare industry. The North America Entertainment industry is the largest in the world reaching over $660B across motion pictures, television programs, and commercials along with streaming content, music, video and audio recordings, broadcast, radio, text and book publishing, eSports, and video games sectors [6]. In Healthcare, the US spends a massive 19.7% of GDP which includes in part technologies such as wearables, telehealth, and mobile health applications (the year 2020 data from [7]). DWE technologies applied to these industries have the potential for large economic and societal impact

3 RESEARCH AND TECHNOLOGY DIRECTIONS

3.1 Challenges and Requirements

In addition to the societal and economic challenges mentioned in the previous section, some technological challenges have to be overcome to realize DWEs. These challenges result from the fact that either some related technologies have not reached their full maturity or that DWEs are opening a new set of fundamental challenges to be addressed through exploration and research.

In this regard, DWEs require new solutions, devices, and related applications to meet DWE requirements, e.g., compute capacity, latency, efficiency, power consumption, physical dimensions, and weight.

Advancements in component technologies in the semiconductor industry will be required as they will serve as the cornerstones for 6G enabled DWEs due to their strategic importance across multiple industries and sectors and their long investment/life cycle. Science and technology development in basic material, device science, circuits and systems, and large-scale advanced manufacturing capabilities will have profound impacts on various aspects of the 6G ecosystem which will enable DWEs. Some challenges to be addressed in this context include: enablement of new 6G frequency bands based on advanced semiconductor packaging, RF components, and antenna technologies; empowering baseband modems for exponential data rate scaling while maintaining high processing power efficiency.

DWE use cases might push today's networks to their limits with respect to their requirements. Some use cases might require network capacity far beyond what is possible today, i.e., post-Shannon capacity, might have extremely stringent latency requirements, and/or might be extremely sensitive to jitter. Other use cases might require a highly dynamic (compute) resource/function allocation and larger availability of them. All these challenges warrant new design and networking solutions in the 6G system.

Another big challenge is the attainment of seamless interaction between the physical and digital worlds to facilitate an immersive user experience. This results in technical challenges regarding human-in-the-loop solutions, multi-sensory precision, new methods of human computer interactions, and perceived real-time remote access and control – amongst others.

As DWEs will be deployed at a global scale for everyone and anywhere and will support various use cases with a heterogeneous set of requirements, novel system-wide dynamic and flexible solutions have to be developed to deal with the complexity and provide scalability in order to develop personalized solutions by considering privacy and security aspects.

Finally, a way for generalization and openness to support the heterogeneous technologies and use cases as well as allow for the co-existence of multiple (cloud/service) providers within DWEs will require generic and flexible platform solutions, standardization, and a related global ecosystem.

3.2 Research and Technology Areas

Several technological advancements will be needed to address the aforementioned technical challenges and fully realize DWEs. These technology advancements will require research institutions and industry alike to continue to push the innovation envelope in several key areas including devices enabling DWEs, Human Computer Interaction, NextG networks, AI/ML, and distributed and spatial computing.

Devices enabling DWEs: DWE devices play a vital role in bringing DWEs to reality. Devices enabling DWE are envisioned to be comfortable, affordable, and energy efficient. These devices are expected to have tracking sensors, cameras, compute, displays, and lenses. Some of the current trending devices towards DWE are emerging. 6G communication anticipates a majority of the compute and sensing to be performed from the access point and edge computing to make DWE devices lighter and energy efficient. DWE devices - to be energy efficient - will use energy harvesting such as natural energy sources or RF signaling, which includes Ambient Backscatter Communication (AmBC), compressed sensing (CS)-based random access techniques, and reconfigurable intelligent surfaces (RIS), all potential research directions of interest. Technology never sees the light of success without being affordable, hence DWE devices and operator services are expected to evolve with a variety of price ranges to benefit everyone.

Immersive Human Computer Interaction: DWE merges physical and cyber spaces to transform the physical world into a digital world. Cyber Physical System (CPS) for DWE is a network of huge numbers of interacting haptic sensors (tactile and kinesthetic) with physical input and output. Human Computer Interaction (HCI) is one of the core technologies to bring DWE to reality. HCI revamps the conventional Command User Interface (CUI) and Graphical User Interface (GUI) technologies and transforms them into a more natural User Interaction (NUI), which allows users to communicate in the most human natural way such as through voice, facial expression, movement gesture, moving body, or head rotation. With the advent of skin-like materials and devices within the XR research field, various tactile sensors are under development. Vibro-haptic - for mechanical feeling by vibration- and thermo-haptic - for thermal feeling by heating or cooling- are some of the haptic sensors actively considered for DWE. Though CPS transforms DWE to the digital world, it gives rise to a huge volume of haptic sensors to be networked. 6G communication is expected to support such new application, bandwidth, and data rate requirements (e.g., massive Broadband URLLC connectivity is the class to meet these requirements). Hence, there is a broad range of research directions to be explored to enable immersive HCIs ranging from skin-like materials, haptic codecs (e.g., IEEE P1918.1.1), networking of haptic sensors, and CPS, among others.

NextG Networks: DWE involves visual, audio, and haptic sensors to communicate with the digital world. The human brain takes up to 10 msec to understand the visual information and any jitter or longer latency tends to cause simulator sickness to the DWE users. However, it takes up to 100 msec to decode the audio signals. Due to the tight synchronization of the reaction of human brains to the haptic sensors, DWE urges sub-msec to 1 msec to instantaneous haptic feedback and tactile signals [8], respectively. Failure to meet these latencies and reduction in jitter will result in conflicts between visual and other sensory systems leading to cyber sickness for the DWE users. The 6G network is anticipated to introduce new spectrum frequencies (e.g., sub-THz bands) and classify a separate class of applications to serve the strict latency and to reduce jitter. In addition, integrated support for joint communication and sensing will generate opportunities for new and interesting DWEs. For example, the capability for sensing the position and distance between objects and users with cm-level precision will enable enriched personalized shopping experiences as well as richer interactive XR experiences. The architecture of the 6G network will also continue to evolve and provide enhanced network coverage and reliability needed by DWEs. This will provide users with increased network coverage, performance, and reliability such that they can enjoy DWEs as they travel and move about during their daily routines.

DWE empowerment through AI/ML: 6G will be the era of mobile intelligence much like 4G was the age of mobile Internet. AI/ML is expected to penetrate every layer of the 6G ecosystem. AI/ML will become a key technology to realize the 6G vision of enabling a fully autonomous network operation and automation with extreme flexibility to achieve dynamic network and air interface adaptation. All of this will be key for serving a much more diverse set of DWEs while substantially improving network operation efficiency. More fundamentally, AI-based air interface design and air interface enablement for distributed computing and intelligence will allow end-to-end native AI and true convergence of communication and computing. AI/ML will also play a key role in ensuring network security and trustworthiness by allowing the system to learn, detect, and respond to threats autonomously. All this does not only imply the need for AI-native 6G design and the implementation of AI-based solutions within 6G networks but also enhancements and research in AI/ML to develop more tailored tools.

Computing technologies advancing DWEs: Facilitating immersive experiences for emerging applications for everyone in a world where physical and digital dimensions merge seamlessly require additional computing enhancements. Spatial computing is the virtualization of activities and interactions between machines, humans, (physical or virtual) objects, and the environments in which they take place to enable and optimize these actions and interactions [8]. It is a paradigm in computing reflecting a technological area of relevance for DWEs. Another relevant computing technology is distributed computing. Solutions that will seamlessly coordinate shared computing resources and functions from multiple computing devices/entities by helping them communicate with each other to achieve their individual tasks and to guarantee the service requirements of DWE applications. This is particularly challenging in a highly dynamic environment such as the digital world, where the cardinality, the topology, and the overall structure of the system is not known beforehand and can change. Distributed computing offers advantages in scalability (i) through a "scale-out architecture", (ii) performance via parallelism, (iii) resilience via redundancy, and (iv) cost-effectiveness using low-cost, commodity hardware.

Security/Trustworthiness: To enable DWEs, the security and trustworthiness of 6G networks will be critical. Upper layer security enhancements, in conjunction with potential new PHY/MAC security mechanisms, are expected to protect user security and privacy, as well as overall network security (by protecting the user data used for network-side training). Decentralized identity management and/or data provenance technologies may potentially enable new classes of (user equipment) UEs such as low-power IoT devices to further expand the functionality of the 6G cellular network system. Quantum/post-quantum security is a forward-looking technology direction to ensure security against disruptive quantum computing technologies and the computational power of adversaries in the next several decades.

Digital Twin: A virtual representation in the digital world of the physical world objects is known as a digital twin. Objects can be any copy of physical world objects such as a human, animal, tree, table, chair, etc. Digital twins are challenged with security, quality, authenticity, compliance, and traceability. Digital twins can be integrated with emerging technologies such as blockchain and spatial computing. Further, there are ongoing areas of research to address these challenges such as a mathematical representation of digital twins and their associated physical objects, and spatial data mapping - whose multidimensional data storage technology is a promising research direction for the future. A digital twin, may be used in a broad range of applications such as design and education in non real-time, or monitoring, control, management, and prediction in real-time. Control of traffic, crowd safety, and mobility, in cities, or streamlining productivity of robots and vehicles, and prevention of accidents, in mines, are examples of the latter.

Distributed blockchain: Now that we have devices enabling DWEs and digital twins, another important aspect of DWE is security. How do we secure a digital twin in the DWE? After a great success in cryptocurrency, blockchain is looked upon for Digital twin security. Blockchain is based on a ledger, distributed among all the participants. Blockchain originates with a genesis block, and every new block is appended to this blockchain using a hash value derived from the parent block. Every block in the blockchain will have a header and transaction data. This chain grows continuously as blockchain users perform transactions. Transactions in a block are packed by a miner- who records and packs a batch of transactions into a block by solving Proof of Work (PoW). This newly mined block is broadcasted to the whole blockchain, all nodes validate it and arrive at a mutual consensus on its trustworthiness. Blockchain is immutable, decentralized, and transparent.

Common DWE Ecosystem: The DWE universe is made up of multiple virtual worlds such as gaming, education, shopping, recreation club, etc., Each virtual world requires services and features such as reputation, persistence of past experience, purchase of artifacts, skins, past experience, etc. The DWE universe encompasses many virtual worlds and offers services spanning across these worlds to convert currencies, artifacts, and experiences from one world to another.

4 PATH TO REALIZATION

For the realization of DWEs, several developments and efforts across the industries involved will be needed as illustrated in Figure 2.

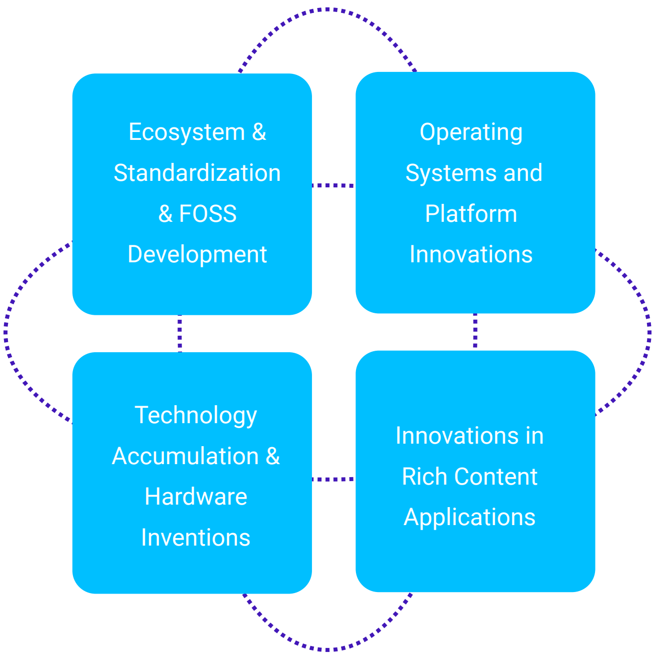


Figure 2 - Key aspects of interest for the realization of DWEs.

Ecosystem, standardization, and FOSS development: Given the highly interdisciplinary nature of DWEs, ranging from hardware over software and networking to applications, multiple sectors will play a pivotal role in the realization of DWEs. A tight collaboration between the communications and computing communities as well as policy makers, applications developers, and end users including new players (e.g., startups, open-source communities) will be required to create a thriving DWE ecosystem.

Enabling technologies in communications, computing, and devices are envisioned to form a foundation upon which standards organizations will define specifications that tie these technologies together empowering a prospering DWE ecosystem and marketplace for emerging applications and services. While innovation will be needed for evolving DWE enabling technologies, free and open-source software (FOSS) solutions and industry standards for proof of concepts and exploration as well as a marketplace will be inevitable. Here, the advancement towards 6G will leverage the strength across industry sectors, academia, open-source communities, standards development organizations, and government, where each stakeholder will play a crucial role.
Standardization is vital for interoperability and achieving global-scale solutions. It is expected that the third Generation Partnership Program (3GPP) will continue to be the leading organization on 6G system specification development. With 6G heading towards being more data-driven and cloud-native, 6G-related standardization would also evolve to accommodate computing and data components. A related standardization effort has been ongoing within the IEEE P1918.1. WG that defines a baseline standard for the Tactile Internet and the Haptic Codecs. An increased collaboration, however, between standards development organizations and other implementation communities/bodies such as 3GPP, IEEE, IETF, Linux Foundation, etc. is expected to pave the way for landing specifications into implementations.

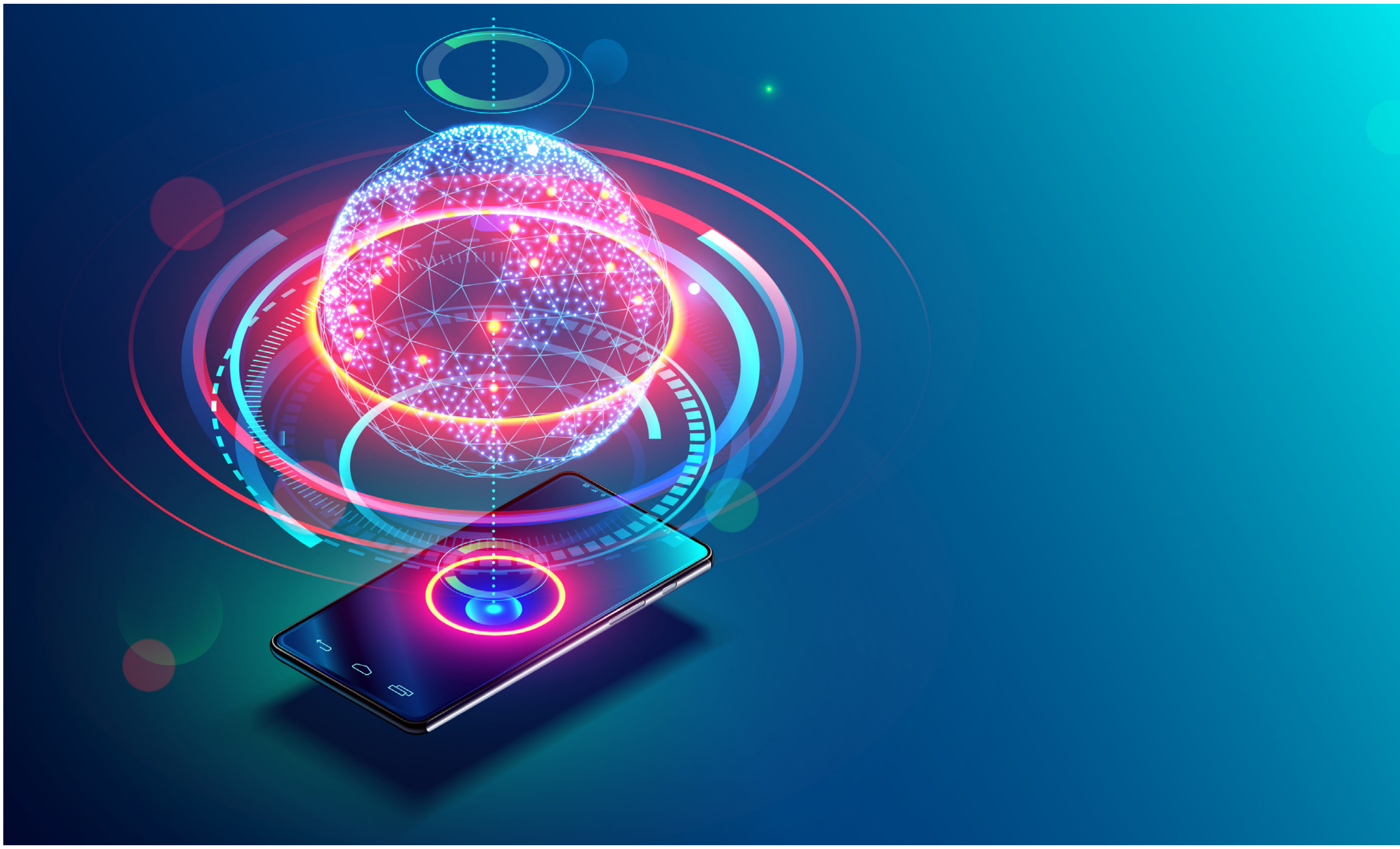
Building pervasive, open, and inclusive solutions for DWEs at a global scale will require cooperation and coordination between a constellation of international standards organizations. Here, the maximum potential of DWEs will be best realized if it is built on a foundation of additional open standards. A related recent forum, the Metaverse Standards Forum, provides a venue for cooperation between a constellation of international standards organizations (e.g., W3C, Spatial Web Foundation, OpenAR Cloud) to coordinate requirements and resources for fostering the creation and evolution of standards in relevant domains. This is only one of many related efforts expected in the near future.

Operating systems and platform innovations: As the hardware market is not yet well developed for DWEs, it is not yet determined how many mainstream operating system platforms there will be. Ideally, solutions and platforms should be flexible enough to support various operating systems for DWEs. In terms of software, the operating system and platform are also crucial considerations. Enabling an efficient developer ecosystem, in this context, is also an important aspect to foster innovation and build an active content development ecosystem.

Technology accumulations and hardware innovations: In the growing market, digitalization and related applications (e.g., XR) have gradually built an ecosystem consisting of multiple players such as computing platforms, hardware suppliers, content application vendors and users, and infrastructure providers like mobile operators, cloud service providers, and network service providers. This provides a basis for the healthy development of the DWE ecosystem. Following the early stages of technology development and breakthrough in the context of DWEs, however, the accumulation of various related technology areas and evolutions therein as well as innovations in hardware will play a pivotal role in the realization of DWEs. While the related industry has already evolved from a few companies, such as hardware manufacturers and application developers working alone, more needs to be done towards a multi-party ecosystem cooperation model, in which all parties involved are working together to build a thriving ecological environment, and all parties in the ecosystem are accelerating technology integration and innovation.

Innovations in rich content applications: 6G is anticipated to provide a new system and networking capabilities and services that go beyond legacy communication services. Application innovations, particularly applications with rich content for DWEs, are needed to exploit the full potential of these capabilities to enable immersive experiences. Application innovation is therefore a crucial step to prepare the end users and the market and achieve the full business potential of 6G and DWEs.

These developments contribute to the realization of DWEs, along with design imperatives and considerations consistent with motivations and audacious goals. These considerations include environmental and economic sustainability with energy and cost efficiencies, trustworthiness with security and resilience, DWE service versatility and user device diversity, and simplified operation, among others.



5 CONCLUSION

DWEs are expected to deliver immersive experiences to anyone, anywhere, at any time. This provides societal, economic, and technological opportunities to bridge the digital divide, foster the North American and global economy, and develop innovative solutions. A highly interdisciplinary approach with the involvement of multiple industry sectors including, mobile operators, cloud service providers, network service providers, hardware manufacturers, and application developers will be required to realize the full potential of DWEs. Furthermore, a collaboration between industry, academia, open-source communities, and standard development organizations will be essential. Research and innovation are required in the areas of hardware, immersive human-computer interaction, networking, AI/ML, computing technologies, security and trustworthiness, digital twins, distributed blockchain, and common ecosystem development.

With the emergence of new applications, technologies, and market opportunities, DWEs will be empowered by the expanded capabilities and services of 6G systems and are expected to enable revolutionary technologies, business models, and applications, bringing convenience and experiences that are unthinkable today to everyone.

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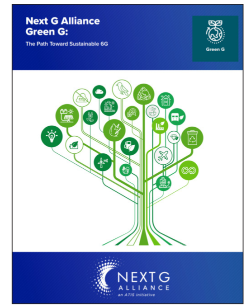
NEXT G ALLIANCE REPORTS

6G Technologies

6G Applications and Use Cases

Roadmap to 6G



Green G: The Path Toward Sustainable 6G

6G Distributed Cloud and Communications System

Trust, Security, and Resilience for 6G Systems

Digital World Experiences

6G Market Development: A North American Perspective

Building the foundation for North American leadership in 6G and beyond.

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