Opportunities and Challenges of Tangible XR Applications for 5G Networks and Beyond

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***Abstract*—The increasing popularity of virtual reality (VR) and augmented reality (AR) applications has unveiled the need for boosting the efforts of implementing extended reality (XR) to users. An analogous high interest from both academia and industry is being shown for tactile internet (TI). The ever-increasing use of virtualization technologies makes the usage of haptic communication even more important in order to create robust tangible systems, but also to achieve an optimal and faster balance among the interaction modalities, as well as between humans and machines. The current wireless mobile networks cannot provide ultra-low latency, massive computational capability, and high communication bandwidth, requirements which are crucial for applications such as extended reality and tactile internet. A simplified tangible XR system is proposed accompanied with the opportunities and challenges of such an implementation.**

***Index Terms*—5G Networks, Extended Reality, Haptics, Tactile Internet.**

I. Introduction

The emerge of extended reality (XR) occurred in an effort to answer the mobile virtualization interconnection challenge as well as of a future tactile internet (TI) which allows remote interaction in perceived real-time with real and virtual objects or systems. XR services enclose several flavors of realities like virtual reality (VR), augmented reality (AR), or mixed reality (MR) technologies as well as TI with the purpose of enabling the transmission of haptic signals, such as the feeling of touch. The outcome of merging these technologies goes by the name of tangible XR. Interesting fields which can take advantage of such a technology include sectors like entertainment [1], education [2], culture [3], healthcare [4], and autonomous driving [5].

A simplified design of a tangible XR system is described which can find application in the abovementioned industries. Users applying tangible XR enter in a so realistic virtual environment which gives the feeling of being in the real world. In this digital world, the users can interact each other using haptic interfaces, offering them an experience similar to the real world. The behavior of human end users shapes while engaging with XR, TI and other similar cutting-edge technologies, and therefore they should incorporate unique prerequisites for user satisfaction.

These requirements are closely addressed by the fifth generation (5G) networks specifications. 5G system’s full potential aims to provide enhanced mobile broadband (eMBB) data rates, massive machine type communications (mMTC) to increase network reliability, and ultra reliable low latency communication (URLLC) to solve latency issues [6]. However, emerging technologies like tangible XR systems, raise the bar of unique challenges that mobile networks must confront. Thus, a revolutionary sixth generation (6G) wireless system may be required to overcome the network challenges. Past and emerging trends will merge under the drivers of 6G enabling new network services regarding capacity, reliability, and latency. Among these three parameters, minimization of latency consists of a crucial matter for a successful data transfer of sensitive applications, but still current mobile networks cannot achieve the desired value.

Although, tangible XR systems will introduce new applications, several challenges that will emerge are described as well. An efficient and effective application of such a sensitive technology, requires the investigation of the aspects that may harm its appliance. The description of these challenges aspires to provide insights for further research.

This paper is organized as follows. Section 2 presents the XR and TI requirements and challenges, and proposes a tangible XR system model. Section 3 describes the challenges that cellular networks have to face in order to support such sensitive technologies. A brief discussion on new network services that may arise is given in Section 4. Section 5 focuses on future application domains that could take advantage of tangible XR and Section 6 highlights the open issues of applying such a technology through mobile networks. Finally, Section 7 concludes the article.

II. Extended Reality and Tactile Internet

The combination of Extended Reality and Tactile Internet is anticipated to unveil an unprecedented technological leap that will radically redefine standard 5G services.

A. *Extended Reality*

Since there are no clear boundaries between concepts related to virtualization applications and the produced results as they interact with users tend to overlap, it is significant to first define the concepts and their relation to each other. The basic structure

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of VR technology is the creation of a digital environment [7]. AR is a much realistic realm than VR, where through the augmentation of information the user interoperates with a more detailed environment [8]. Thus, virtual reality (VR) places users in a virtual environment, while augmented reality (AR) is best described as the system of presenting virtual information over reality. The combination of them is called mixed reality (MR), which presents these technologies in a merging state of virtual and actual environments [9]. Actually, MR is an immersive technology that merges the physical and the real world to provide a new virtualized environment where physical and digital items and objects coexist and interact with each other in real-time.

XR is a term that incorporates all virtual or combined real-time depictions of the environment, including VR, AR, and MR [10]. These applications are based on the degree to which the technology produces immersion, to offer the user the corresponding experience, while this fact becomes even more important when this technology is used in critical social and economic sectors. Future XR technologies may realize novel, unprecedented types of reality. Actually, XR may be rather viewed as a placeholder for future yet unforeseen developments on the digital frontier.

Due to the cellular networks data transmission limitations, which struggle the possibilities of exploiting XR, its existing uses are mainly commercial in nature and aim at selling XR products in the field of entertainment. However, the utilization of the possibilities within the above applications is limited, due to the latency constrains, which must be limited to a few milliseconds, as presented in Table 1, so that the user can have a high-quality experience, but also to be able to perform the corresponding sensitive tasks that correspond to the above areas [11].

Even the upcoming 5G networks may not be able to offer the absolute XR experience to the user, as they may not be able to provide the necessary low latency. In such a way, there is no possibility of utilizing the sensory systems of XR technology, so to form a fully immersive experience for the user. A truly exciting visualization experience requires the combination of the mechanical aspects of the system (computing, processing, storage, equipment) but also the sensory ones which include the human senses and mainly vision, hearing, and touch. All the aforementioned must be considered when designing the systems, to form the necessary "realism" in the user experience. Achieving the above goal requires the introduction of new concepts such as quality control of physical experience (QoPE), a concept that is the combination of quality of service (QoS) and quality of experience (QoE), which relate to mechanical and sensory aspects, respectively. To explain better, some factors that affect QoPE are the knowledge of brain function (e.g. the ability to capture experience from the sensory centers of the human brain), human physiology (e.g. the way the human body reacts to various stimuli), and kinesiology (e.g. user gestures). In short, the necessities of XR services are a mixture of traditional URLLC and eMBB with built-in perceptual factors that must be supported by future generations of the mobile network [12].

B. Tactile Internet

Haptics is the latest technological field and concerns the reception, transmission, and display of elements related to the sense of touch. The haptic sense works in parallel with the auditory and visual ones, for a person to receive information from the environment, which is related to the interaction of forces. The types of haptic data are the kinetic and the tactile ones [13]. Kinetic data refer to the forces exerted on the human body by the environment. Tactile data describe vibrations, a prerequisite for almost all neuromuscular activities, such as the blind perception of objects and the determination of surface properties.

Tactile communication can be either real-time or offline. Real-time communication presupposes the minimization of latency, to transmit directly the data packets that compose the tactile information. Tactile internet is the means for the application of communication and interaction technologies of different users, within remote environments, through the transmission of tactile information. As of offline communication examples are recordings of telepresence and teleaction (TPTA) sessions, interaction performance evaluation, and assisted learning. Due to the lack of real-time interaction, the issue of device latency and computability does not affect the application. Tactile data communication can also be classified by transmission media, as tactile applications have traditionally used wired networks to transmit data packets, but recent developments in telecommunications, and in particular the development of 5G, enable to explore the possibilities of technology in wireless transmission.

Due to high requirements of transmission rate, channel delays, and jitter, standard communication protocols fail to support haptic data. Acceptable parameters for tele-haptics require a few milliseconds for both network delay and jitter, as shown in Table 1. Therefore, present compression techniques with a few milliseconds delays cannot be used in haptics [14].

TABLE 1 TYPICAL REQUIREMENTS OF VIRTUALIZATION AND TACTILE TECHNOLOGIES [11]

Technology	Delay	Latency	Data rate
XR	≤ 20 ms	≤ 1 ms	1 Gbps
TI	≤ 50 ms	≤ 1 ms	100 Mbps

According to Table 1, it should be concluded that XR and TI are considered as very sensitive technologies for wireless data transmission. Strict network specifications should be fulfilled in order to produce a smooth and uninterrupted user experience. The demanding requirements in terms of delay, latency, and data rate of both technologies, are expected to be addressed by the next generation networks, creating the circumstances to unveil the full potential of their implementation in a wide scale.

The combination of XR and TI consist of a new term named tangible XR. A simplified design of tangible XR is illustrated in Fig. 1. Through this technology, the users enter a digital environment, with which they interact not only with the use of digital equipment, but also mentally, as this environment responds to all the users' senses, offering them an experience similar to the real world.

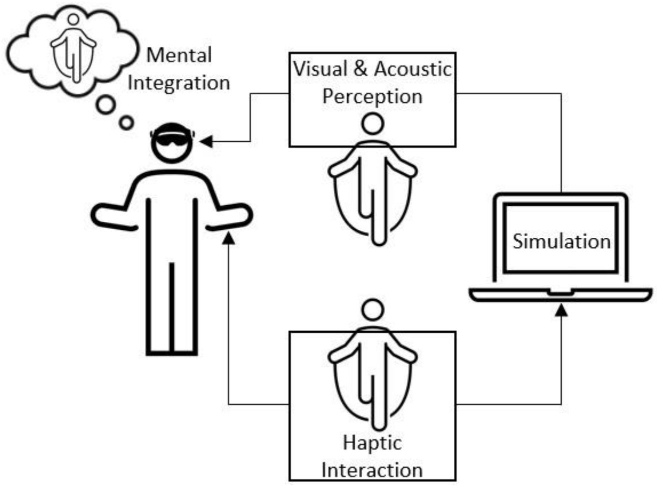

Fig. 1. Tangible XR system model.

III. MOBILE NETWORK CHALLENGES

For 5G tecnology, three major categories of services have been confirmed by the International Telecommunications Union (ITU): eMBB; mMTC; and URLLC. However, due to the high demands on efficiency, latency, and computing resources, even 5G networks may not be able to assist the development and wider application of future technologies. This fact is remarkably crucial for the urban development of technology, and the parallel use in a wide range of population [15].

Of the aforementioned three categories of 5G services, eMBB is so far the most advanced, due to the development of the necessary data transfer speeds of 10 to 20 Gbps [16]. The development of URLLC, on the other hand, is at a very early stage due to the differences in the statistical treatment of the data contained in this technology [17].

Tangible XR technology lies in between of the abovementioned 5G services as it operates at speeds from 100 Mbps, providing a resolution of 1K, to up 1 Gbps which enables the perception of the environment, comparable to the human eye resolution [18]. However, the application of this technology is characterized by time delays, latency constrains, and synchronization issues between visual, audio and tactile responses due to the wireless nature of the mobile networks [10].

The communication flow of tangible XR is depicted in Fig. 2 [19]. The communication is unidirectional, and for the upload and download data regarding content installation time, a rate of few milliseconds may be acceptable. However, in parallel with the synchronization of the audiovisual, there should be synchronization of the tactile data, so that the experience is complete. The concept of “complete” experience refers to the correlation of the visual, auditory, and tactile parameters of the medium. By nature, humans rely much more on tactile sensation than acoustics or visuals, so viewing a video with a content-responsive tactile aspect can provide a much more complete experience. The expectation for these technologies concerns the overall experience and not the exclusive provision of audiovisual data. However, full synchronization of these three parameters/senses will always be the main goal of QoPE, as the evolution of network technologies, combined with advances in equipment manufacturing and optimization, will allow further development of the field. Reliability will continue to play a critical role in the development of these technologies, even with the implementation of intermediate solutions, as extensive coding can still lead to a high degree of reliability and is even considered as 5G reliability solutions.

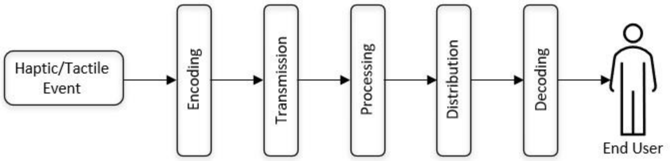

Figure 2. Tangible XR communication flow.

An emerging development of the 5G networks and beyond is the millimeter wave (mmWave) band, which operates in the frequency range of 30 to 300 GHz, and the exploitation of THz bands, which support a wireless connection of multiple Gbps. The use of this medium seems a promising approach in the installation and operation of XR and TI systems, as the transmission of the signal at these higher frequencies allows the reduction of latency and the development of high data transmission speeds in one receiver but also in many receivers, as well.

A. *Capacity*

Utilizing mmWave band is an optimal solution to the problem of lack of availability of sub 6 GHz frequencies. The use of mmWaves is not only an “opening” in accelerating the application of tangible XR technologies but can offer a UHD quality environment [18]. Communication through mmWaves grants an instantaneous channel capacity increase if the transmitter and receiver are in line-of-sight (LOS). Nevertheless, mmWave links are vulnerable to blockage and beam misalignment [10].

B. *Latency*

There are manifold aspects that contribute to the specifications of tangible XR as it necessitates an end-to-end latency of 1 ms, which is not feasible from the current networks. 4G technology achieves a round trip latency of 15 ms, while 5G is expected to reach an end-to-end latency of 5 ms [20]. Exploiting mmWave band is anticipated to play a considerable role in diminishing the latency as the distance between the transmitter and the receiver is shrunken. Thus, it is anticipated that mmWaves will reduce end-to-end latency to 1 ms [10].

C. *Reliability*

The concept of reliability is directly related to how the signal is transmitted from the transmitter to the receiver, as it is used to describe the guarantee received by the receiver regarding the quality of the signal, while the most acceptable form that this concept takes is the reception of the signal at 99.99999% of the transmission time. However, the concept of reliability often takes a different form and is reflected as the latency limit that the signal provider allows to the user.

Regardless of the conceptual approach, reliability plays a critical role in the development and operation of tangible XR technologies due to signal exclusion. The adoption of mmWave band to transmit the required high data rates has the disadvantage of dealing with a more vulnerable channel, mainly due to signal blockage. To address this phenomenon, multi-connectivity networks have been developed, which include various techniques for increasing connectivity and effective data transmission.

Table 2 depicts a matrix of technological enablers to improve capacity and reliability, and to reduce latency in wireless communication related to tangible XR [10]. These are the three parameters that are on the top of every research regarding wireless systems, as they affect their performance. Current wireless systems still struggle to support the demands of emerging and sensitive applications. Thus, the evolution of several technologies could assist for improving wireless data transmission and eliminating today's barriers. The involvement of emerging technologies to support mobile networks could create a great framework to address the aforementioned issues.

TABLE 2 MATRIX OF TECHNOLOGICAL ENABLERS TO REDUCE LATENCY AND IMPROVE CAPACITY AND RELIABILITY

	Proximity-based Computing	High Capacity Links	Proactive Computing	Edge Machine Learning	Parallel Computing	Multi-connectivity	Task Replication	Extreme event-aware Design
Capacity		✓						
Latency	✓		✓	✓	✓	✓	✓	
Reliability					✓	✓		✓

IV. NEW NETWORK SERVICES

The key requirements for 6G systems may be summarized as follows [21]:

- Data rate of more than 1 Tb/s which is at least 50 times larger than that of 5G systems.
- User experience data rate of at least 10 times more than the corresponding value of 5G.
- Latency less than 1 ms that should be at minimum a factor of 40 times better than in 5G.
- Mobility is expected to support up to 1000 km/h to include mobility values encountered in commercial airplanes.
- Connection density per km^2 could be 10 times that of 5G, given the desire to support an Internet of Everything (IoE).

Thus, beyond 5G services higher data rates and lower latency are expected to extend 5G capabilities by reshaping classical eMBB, mMTC, and URLLC to introduce new services in the future 6G networks.

A. Mobile Broadband Reliable Low Latency Communication

To support XR or TI applications, the discrepancy between eMBB and URLLC will no longer be viable, due to their requirements in reliability and low latency, but also high level of data transmission. Therefore, a new category of services called mobile broadband reliable low latency communication (MBRLLC) enabling the development of high-reliability 6G networks should be developed. This technology will combine eMBB and URLLC technologies to create a novel technology that is energy efficient and will not be affected by the high demands of 6G devices [12].

B. Massive Ultra Reliable Low Latency Communication

Existing URLLC technology can meet the reliability and low latency requirements required for XR and TI application development, however 6G should maximize device interconnectivity by merging URLLC into a massive ultra reliable low latency communication (mURLLC) that includes present URLLC with mMTC. This service will create a platform in which reliability, latency and scalability tradeoff will improve the network designs, taking into account the architecture, reliability, data size, topology and decision-making process, under the influence of uncertainty [17].

These services enable new performance objectives and requirements that should be gradually addressed, firstly during the beyond 5G evolution, and then at the disruptive 6G implementation, as shown in Table 3 [12]. The constant progress of the cellular networks consists of a crucial factor for the development of novel systems. Evidently, future applications require instantaneous and extremely high-speed wireless connectivity. The introduction of new, unlicensed yet, frequency bands will contribute to both the minimization of network latency and improvement of data rate and reliability. The research for the next generation cellular systems has already started in order to meet the requirements set until 2030 [21].

TABLE 3 NETWORK SPECIFICATIONS

	5G	Beyond 5G	6G
Services	eMBB mMTC URLLC	mMTC Hybrid (URLLC+eMBB)	MBRLLC mURLLC
Data Rate	1 Gbps	100 Gbps	1 Tbps
Latency	5 ms	1 ms	< 1 ms
Reliability	99.999%	99.9999%	99.99999%
Frequency Bands	Sub 6 GHz mmWaves	Sub 6 GHz mmWaves	Sub 6 GHz > 300 GHz THz bands

V. FUTURE APPLICATION DOMAINS

Many opportunities and challenges arise from the adoption of tangible XR in the entertainment, education, arts, culture, medicine, autonomous cars, and human-computer interaction domains.

A. Entertainment

Online gaming is one of the earliest and most common sectors for providing virtualization technology. Due to the existence of a set of stimuli during gaming like vision, sound, and touch, tangible XR is an ideal example of examining the effectiveness and efficiency of this technology. The XR computing comes from several factors: a higher refresh rate of 60-120 frames per second to provide two synchronized images for both eyes; a 120° field of view that is twice that of traditional games; and most importantly, the need for immediate visual and tactile feedback due to the often-changing perspective.

The movie "Ready Player One" directed by Steven Spielberg envisions that several types of wearable interfaces from gloves to full-body suits and headsets generate a tangible XR experience through different interaction modalities. Emphasizing in peripherals, like wearable devices, to create a comprehensive design framework for entertainment, an examination of their performativity, sociality and interactivity is on the top of research projects [1].

B. Education

The use of virtualization technologies in the field of education has recently gained a certain reputation. The adoption of TI can offer an additional parameter, where the user receives all the experience offered by the system, allowing the development of even more interactive educational scenarios. The application of the above can be applied by tangible XR systems. The synchronization of audio, video, and haptic parameters plays a critical role in shaping an educational experience, which will be significantly improved by advances in the field of application of tactile technologies.

The renovation of a conventional classrooms into smart and interactive ones consists of the next step in students' education. Such a classroom combines 3D virtual services with haptic actuators in order to engage the students and enhance their learning process. A smart classroom applying tangible XR technology sets aside the traditional teacher-center way of teaching and in addition gives the opportunity to disabled or visually impaired people to attend and interact with the environment [2].

C. Art and Culture

Virtualization technologies are already being used in several museums and galleries around the world to provide users with an enhanced exhibit experience. The virtualization of information is highly localized and the information need to be updated at a fast rate as the user moves to the next object. With the maturing of tangible XR more computationally intensive applications are expected to emerge like an art installation in a metropolitan area that enables the residents to participate and interact with the scenes and with each other in the virtualized environments. These applications may drive to hundreds or thousands of participants located in a geographically large area who should be provided with high throughput, and low latency communication, which is rather challenging.

An open-source Internet of Things (IoT) framework called Interactive, Responsive Museum Experience (IRME) combines tangible XR technologies. In this framework VR, AR, haptic interfaces, and 3D imaging are utilized by museums to stimulate visitors and engage them with the exhibits. Incorporating tangible XR technology, museums will attract more visitors, including visually impaired people, as they will be able to touch the exhibits [3].

D. Healthcare

One of the most promising areas of virtualization techniques development is the healthcare sector. The further development of TI can unleash the improvement of applications in this field. The development of tangible XR will lead to improved efficiency in the demanding procedure of remote surgery, by enhancing the ability to interact with the patient and perform precise actions.

A cloud-based tangible XR system assisted by 5G can be useful for surgery simulation, treatment support, surgical training, and medical education. A tangible XR system delivers superior experiences that revolutionize the use of content in both the doctors and patients. Such a system can not only transmit medical information of patients but also capture the motion of doctors and patients by sensing their movements allowing a distant surgery operation [4].

E. Autonomous Vehicles

The overall collection of environmental data is critical to the development of fully autonomous vehicles. The development of XR and TI can benefit the sector as the recording and mapping of the vehicle's surrounding environment, can then be transmitted to all vehicles, thus creating a set that provides them with the information they need to improve its efficiency and act autonomously.

With the parallel development of machine learning (ML) applications, a tangible XR system can create a training environment for autonomous vehicles, in which the vehicle receives information not only about the structure of the environment but also about the development of driving customization protocols [5].

F. Brain-Computer Interaction

In addition to human-computer interaction (HCI) and beyond tangible XR, the development of sensory interaction systems is the first step in the development of brain-computer interaction (BCI) technologies. The areas of development of this technology so far are mainly related to the health sector, for the operation of prosthetic limbs in patients with serious diseases or amputations, however, the further development of BCI, combined with the development of wireless implants creates a new technological environment, which is expected to be developed further in the coming decades. The scenarios for the future possibilities of technology refer mainly to the projection of multimedia directly on the human brain [22]. BCI refers to a reality where through the use of discrete devices, implanted sensors in human body or embedded ones in the natural environment, people will be able to interact with the world around him in a similar way to that of using a smartphone. A simple example of this application is the ability to communicate between people using gestures and haptic messages. At the same time, it is possible to develop empathic applications, where the machine will be able to adjust its operation according to the emotions and mood of the user.

The above applications of the future cannot be introduced using 5G networks, due to latency and data rate limitations, but requires the development of 6G technology, which is expected to address the above challenges. As with the tangible XR, BCI require low latency and high reliability to operate efficiently, however, it is much more sensitive than XR and TI to physical perceptions and require QoPE guarantees.

VI. OPEN ISSUES

Despite the numerous opportunities, the utilization of tangible XR still has to face various challenges [5].

A. Quality Control of Physical Experience (QoPE)

For tangible XR applications, Quality of Experience (QoE) needs to be merged with network Quality of Service (QoS), because precise tracking of users and objects is critical in highly localized areas. Thus, failing to locate objects precisely results in degraded QoE even though QoS requirements might be satisfied. To create a total experience requires the combination and simultaneous application of the two. QoE can be further enhanced by extending the use of cellular networks and cloud computing by providing and analyzing emotional feedback from users. In this way, the appropriate conditions will be created for the development of the QoPE, which will be the merge of QoS and QoE.

B. Offloading

The logical conclusion, in any application scenario of emerging technologies, is the finite nature of the computing resources. The development and spread of these technologies will create controversy among users regarding the use of these resources, as in these cases the servers will have unequal access to users, due to the incompatibility of the equipment they will use. The existence of this phenomenon can jeopardize the universality of tangible XR applications, as users will compete on accessing the available resources, in which some users may be left with no or little resources because others dominate computing services by repeatedly offloading. Dealing with this issue, further research needed to ensure fair access mechanisms, both considering selfish behavior of users and network related unfair treatment of users that may arise from users being given less opportunity for offloading due to their poor channel conditions.

C. Content Model

In virtualization applications, usually, the requested frames or data from different users are highly correlated with location. A simple example is a multiplayer football game in a VR environment, where each user has access to the same 360° video, where the viewing angle depends on its location. When correlated content models are used the computational load might significantly reduce. The processing of the correlated content at devices for increased efficiency remains an unsolved issue.

D. Heterogeneous Users

Usually, virtualization technologies presuppose that users are homogeneous. Actually, users are not identical because of the different type of available interfaces. Among different users, the equipment used to access digital services is not the same and is largely related to the user's ability to provide high-quality equipment. The result is the problem of uneven distribution of computer resources, as each set of equipment will have different characteristics, and therefore will offer a different degree of access to computer resources for each user. Providing computation resources on users' local capabilities remains an open issue.

E. User Privacy and Network Security

By nature, all wireless technologies present the issue of user's privacy and network's security, but in the case of tangible XR the problem is magnified. Due to the interaction with the environment, and with other individuals, tangible XR applications will incorporate a vast amount of personal data about users. Such information may be disclosed to third parties causing privacy and security concerns. These topics need to be extensively investigated to develop personal data protection protocols.

VII. CONCLUSION

Nowadays, the popularity of virtualization application increases significantly. It is time for the virtualization technologies such as VR and AR to go a step forward in order to replicate in a more realistic way the real environment. XR promises an excessive user experience through the integration of haptic feedback. The usage of TI in conjunction with XR is able to create robust tangible systems to enhance the interaction between humans and machines. Moreover, taking advantage from the emerging wireless mobile networks that can provide ultra-low latency, massive computational capability, and high communication bandwidth the smooth operation of XR and TI becomes easier.

Tangible XR offers a great potential to increase the immersion into virtualized environments. Such a technology requires demanding specifications to be handled from the network infrastructure. Cellular networks will demand to support very large capacity, ultra-low latency, ultra-high reliability, and massive connection density. To achieve these issues, radical modifications in multiple network domains need to be addressed. Next generation communication systems seem as appropriate candidates due to their unique propagation characteristics and potential for high data rate transmissions. Tangible XR accompanied with 6G clearly deserves more research from both vendors and academia.

This article presents XR and TI with the requirements and challenges that cellular networks have to face in order to support such sensitive technologies, and according to these issues proposes a tangible XR system model. Next generation cellular networks like 6G will enable new network services which will introduce future application domains that could take advantage of tangible XR systems. Though open issues of applying such a technology through mobile networks are still relevant. Unlike other studies, this one differentiates as it describes a simplified and fully effective system that can show its overall potential operating over beyond 5G networks or 6G networks. The parameters that future cellular networks should improve, regarding current networks, in order to provide smooth user experience are capacity, latency, and reliability. Doing so a vast amount of applications would be able to take advantage of tangible XR technology. After a deep analysis of tangible XR systems, it can be concluded that there is an exhilarating prospect that lies ahead. The way to overwhelm the challenges is still full of barriers, but this study offers sufficient visions to inaugurate research toward promising directions.

As video transmission is progressively becoming the dominant choice for today's communications and is evolving to XR, a future work on holograms and multisensory communications is encouraged as they seem to be the next frontiers in this virtual mode of communication. Combinations of tactile interfaces and holograms aiming to provide touch to the latter, could open further applications. Moreover, communication schemes that will be able to involve all the five senses should be considered. The senses of sight and hearing are integrated in audio, video, and holograms but for smell and taste, which are entailed with feelings and emotions, there is no sufficient technology for their transmission yet. Thus, research to enrich virtual experiences with smell and taste remains a topic that needs further study.

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