Conceptual framework for quality assessment in human-centric 6G XR services

V Stoynov\(^1\), A Ivanov\(^1\) and D Mihaylova\(^1\)

\(^1\) Department of Communication Networks, Technical University of Sofia, bul. Kl. Ohridski 8, Sofia 1000, Bulgaria

E-mail: vstoiyov@tu-sofia.bg

Abstract. The 6G communication networks and technologies have to enable the development of wide variety of low latency and ultra-reliable services. Furthermore, the 6G is foreseen to be the era of new devices which integrate our natural human senses in order to create a fully new concept of human-machine interactions. The eXtended Reality (XR) based wearables will surely improve the way we collaborate with modern technologies by merging the real and virtual world in one innovative continuum in order to expand the possibilities of using and interacting with different types of modern or already well-known IT services. In this context, a vital 6G research area is the design of different flexible quality assessment metrics, targets and measures that integrate human perceptions and physical factors from human physiology. This metric design should consider the multisensory nature of XR devices by incorporation of different objective network-related as well as strongly subjective human-related features like sight, touch, smell, taste, body physiology, psychological traits, gestures and even sixth sense. In this paper a conceptual framework incorporating a mixture of new and classical quality assessment constructs like Quality of Service (QoS) and Quality of Experience (QoE) is proposed for 6G networks from human-centric point of view. It considers the development of new types of intelligent XR technologies and give an insight in regard to overall human experience assessment, modelling and prediction.

1. Introduction

The 6G networks’ paradigm will revolutionize our perception regarding the contemporary lifestyle, society, business and communication. The implementation of 6G systems will result in development of numerous new services and corresponding research areas. The main characteristics of next-generation networks - high level of node densification, higher throughputs, and large-scale antenna systems will be provided by new emerging trends that comprise new types of services and the current revolution in new categories of wireless devices - smart wearables, implants, XR devices, and artificial intelligence (AI), computing, and sensing [1].

The 6G networks will be able to establish a reliable and secure connection between a wide variety of smart devices. Furthermore, the communication network will be characterized by diverse types of coverage areas. In this context, it is not possible to ensure just a single global coverage to connect the whole world. For that reason, the communication networks will be divided into autonomous sub-networks. The latter will not be homogeneous but heterogenous – they will be composed by different types of intelligent nodes providing excellent Quality of Service (QoS) to the end-users. Furthermore, 6G networks will be characterised by integration of non-terrestrial and terrestrial communication access, while both are realised by heterogeneous networks by nature. Their different levels of
heterogeneity must be taken into account in order to cost-effectively integrate them together. Consequently, 6G should be able to integrate various heterogeneous components in one secure and reliable continuum which will be a big challenge [2], [3].

Nowadays, an exceptional creation of new types of Internet of Everything (IoE) services is ongoing. For example – the extended reality (XR) services, incorporate different augmented, virtual, and mixed reality (AR/VR/MR) concepts, telemedicine, haptics, unmanned aerial vehicles, brain-computer interfaces, and connected autonomous systems. In this context, these various types of specific applications will disrupt the original goal of 5G networks to support short-packet, sensing-based Ultra Reliable Low Latency Communication (URLLC) services. Consequently, the wireless systems must simultaneously provide high reliability, low latency, and high data rates, for heterogeneous devices, across uplink and downlink. This will result in successful operation of diverse sets of specific services such as XR and autonomous systems. The development and operation of new IoE services will require an implementation of new intelligent and flexible architectures for reliable and secure end-to-end communication, control, and computing functionalities. In order to provide these modern services, exceptional challenges must be addressed. Firstly, it is extremely important to characterise the fundamental rate-reliability-latency trade-offs governing their performance to exploiting frequencies beyond sub-6 GHz. On the other hand, the transformation of wireless systems into a self-sustaining intelligent networks and the orchestration of communication-computing-control-localization-sensing resources personalised for various IoE scenarios are needed [4], [5].

The development of quality assessment metrics that integrate (i) physical factors from human physiology or from a management system for robotics or automation; (ii) psychophysical traits measurements and (iii) cognitive perceptions and behavioural consequences characterization is a vital area of 6G research, especially in the context of new types of intelligent wearables. This requires both real psychophysical experiments and new suitable and flexible mathematical apparatus determination that combine widely known QoS and QoE constructs. The theoretical development of such a complex metric can be achieved using methods from other disciplines, such as operations research (for example, multi-attribute utility theory and machine learning (ML)). Finally, 6G will be the first generation of communication services to use multiple human cognitive feelings which once again provokes the necessity to define new types of human-machine interaction metrics.

This paper provides a basic conceptual framework incorporating a combination of new and classical quality indicators like QoS and QoE in order to design a new construct called Quality of Interaction providing intelligent quality assessment in 6G XR networks from human-centric perspective.

2. Extended Reality concept for interconnected world

2.1. Introduction to XR
New types of impressive technologies are related with diverse forms of realities such as Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), cross reality or eXtended Reality (XR). The expression “XR” is increasingly being used and represents an umbrella term for these technologies (figure 1).

XR-based technologies and services are able to improve the time-space flexibility of users. This can be achieved by avoiding their need to be at the same place at the same time, for example when working on a project. This results in the ability to create faster and more powerful decision-making processes for diverse sets of industries. The remote guidance systems for performing complex tasks such as maintenance and assembly is the main area of XR implementation and operation. Generally, XR will be the next-generation mobile computing platform that unites different types of realities together in order to create an entire new reality-virtuality continuum, depicted in figure 1, thus expanding the human experiences [6].
Both endpoints of XR continuum are represented by AR and VR. The first one – AR, is created by presenting a virtually created information right on reality-based environment. In this context, the user can see through his eyes in real time a mixture of the world around him and virtual objects. This can be obtained only by using additional wearable devices. Obviously, the AR is able to provide the user with additional information that cannot be obtained by using only human senses. AR also has a big impact in education, and it is possible to change the way students will learn in the future. Also, the mobile devices which are used by many people nowadays are really powerful and can be seen as great possibility to use AR-based applications and services. On the other hand, VR bases virtual data as the main focus, having the user operating into the artificial reality virtual environment. The VR environment is created using computing technologies including mainly computer graphics and artificial intelligence. Generally, VR enables the user to perform navigation and interactivity with the virtual objects in a fully virtual situation in a real world. It has many applications, including military, healthcare, education, scientific visualization and entertainment.

The combination of two types of environments results in a mixed reality (MR) concept creation where AR meets VR, by merging the physical and virtual information. In this context, the MR allows users to be part of one environment combining physical objects and digital elements, for example, by the use of semitransparent displays. Furthermore, the operation of MR systems is based on the creation of an illusion that digital objects are in the same space as physical ones. This leads to the requirement each digital object to be precisely situated into the real environment and aligned with the real physical objects in real time. MR comprises systems in which the virtual features are of great importance as well as those in which the physical reality is dominant. Compared to AR, the MR has more virtual objects than physical elements.

Existing online social networking sites like Facebook and Twitter are precursors of what we will come to truly witness when social networking will encompass immersive virtual-reality technology. Actually, social virtual reality lets two people placed in different locations from geographical point of view, thus defining different forms of avatars, to transfer different type of data between them as if they were face-to-face. Also, they can make eye contact and can manipulate virtual objects that they both can see. A serious challenge to the current VR headsets is still the intelligent tracking of gaze direction. Nowadays, there are only few VR headsets able to perform eye tracking. Furthermore, current state-of-the-art VR technology is incapable to read detailed facial expressions and senses. Lastly, the most powerful VR prototypes are wired with cables because the wireless communication mediums created for examples by using 4G/LTE networks are not able to transmit huge amount of high-resolution video at high frame rates. Also, perfect user interface (VR equivalent of the mouse) is still needed [7], [8].

2.2. XR implementation challenges

Application of systems based on XR technologies and services has been proven to be practical and effective way to create the sense of presence and engagement for users to explore inside a virtual-
physical environment. One of the biggest challenges concerning the XR applications design is finding the balance of mixing two totally different concepts - the virtual and the physical (the real). Currently, the challenge of integration of virtual and physical worlds in one continuum has been addressed from different points of view and numerous disciplines, such as computer science, psychology, physiology, sociology and more other. Furthermore, several other important implementation challenges still exist within the application design and development phase of XR services and they can be summarised as follows:

- The VR experience can be accompanied by different symptoms like general discomfort, apathy, drowsiness, headache, disorientation or fatigue which are summarized by the term Motion Sickness (MS).
- The high battery consumption of AR services due to the intense use of sensors causes rapid battery drain on devices which results in limited mobility of the end-user.
- The greatest challenge for Internet of Things-based XR systems is achieving high levels of security and reliability. There are many studies which present a comprehensive surveys on security in IoT, highlighting an extensive list of issues from poor authentication controls to lack of encryption in communications.
- Definition and analysis of specific functional, performance and ergonomic requirements and characteristics for design of secure and reliable next generation XR systems.
- Definition, measurement and modelling of human perception-based QoE criteria for next-generation XR systems and devices using objective, subjective and hybrid approaches.
- Providing a high communication reliability and traffic safety for autonomous vehicles with XR functionalities.

3. Basic conceptual framework for quality assessment

The haptic XR applications being promising solution for 6G system implementation and development, there is still not clear determination of user experience when interacting with such new variety of devices and systems. Objective measurement or prediction of XR communication characteristics through a suitable evaluation model is highly needed. New specific QoE design for haptic virtual environments is obligatory in order to evaluate the user experience in the context of multi-modality applications. Usually, the traditional QoE metric focuses on the quality of involvement and interaction between the user and the specific application, which is the main difference compared to QoS typically indicating the functionality and the quality of the particular technology used in the application [9]. On the other hand, QoE is not able to determine the whole process of human-machine interaction when XR services are used and the reaction of human body and brain to this reality-virtuality continuum. In this context, it is essential to design a new type of quality assessment metric which considers the variety of different types of devices characterizing the next-generation communication technologies. Furthermore, the measurement process of such metric will require measuring the user’s perception of a plenty of VR applications. In this context, we require not only improved performance measures over the well-established QoS measures but also new flexible modelling approaches in order to deal with one of the most important features of the human-machine interaction - the subjectivity of the user.

In figure 2 the structure of conceptual framework based on new complex metric called Quality of Interaction is depicted. It consists of four basic elements – Quality of Service – QoS, Quality of Psychophysical Experience (QoPsE), Quality of Physical Experience (QoPhE) and Quality of Perception. For each basic element the most important parameters are listed. Each of them has impact on overall QoI determination for the specific XR-based communication environment.

QoI is designed as a complex metric which focuses on human-machine interaction with respect of specific human body and perception experiences when operating in XR systems. In this context, the QoI refers to the reaction of the system as a result of user needs and reaction of the user from physiological, psychophysical and perceptive point of view when interacting with diverse set of applications or services based on usage of intelligent devices. As can be seen in figure 2 QoI design is based on differentiation of two different types of reaction resulting from the human-machine interaction described by network reaction layer and human reaction layer. Therefore, the QoI is
principally subjective metric and can be flexibly modified according to the specific application, context or because of the specifics of user expectation and involvement. Additionally, the QoI indicator is characterised by high level of reliability for XR service providers to convey overall end-to-end system functioning (client, terminal, network, services infrastructure, etc.). Furthermore, QoI design is based on multidisciplinary approach involving user psychology, engineering science, economics, etc. As we already mentioned, the QoI depends on four different sub-elements that directly or indirectly affect the user’s perception towards the XR services. These elements should perform to their best to provide high overall quality of interaction. However, the diversity in these elements makes the QoI estimation rather complex and unpredictable. For that reason, the implementation of different approaches for human reaction prediction based on machine learning (ML) and artificial intelligence is highly desirable. As is widely known, the intelligent ML algorithms are able to automatically learn from the past observations of QoI components’ values to make accurate predictions in the future. Some of the most popular ML algorithms which can be used in QoI prediction are decision tree, neural networks, fuzzy expert system, etc. The QoI estimation system may be composed of ML algorithms in order to learn the correlation between QoS parameters and the subjective QoPsE, QoPhE and QoP. The learning process comprises an important phase of training the algorithm with subjective data set. Thus, it is able to predict the QoI based on any combination of input QoS parameters. It is important to mention that an effective QoI prediction model must automatically re-organise to each new dataset without much complexity and time. Finally, it is still necessary to design modern innovative mechanisms to efficiently correlate user performance parameters from QoS, in real time. A potent basis for them, which is also increasing in popularity is the reinforcement learning of deep neural networks [10]. Such algorithms can use the collected QoS parameters to learn the optimal QoI under particular QoPsE, QoPhE and QoP constraints and thus extend the cognitive capabilities of the system.

![Figure 2. Basic conceptual framework for quality assessment](image)

4. Conclusions
This paper presents a basic conceptual framework based on original Quality of Interaction determination characterizing the human-machine relationship in 6G XR environments. QoI is divided into four different quality assessment constructs defining at the same time the reaction of the specific communication environment (network) – QoS, and the reaction of the human body and brain, described by the QoPsE, QoPhE, QoP. This conceptual framework is a suitable basis for implementation and evaluation of different mathematical models describing human-machine communication in virtual environments. Future work may focus on implementation of different models for QoI estimation and prediction concerning machine learning and artificial intelligence methods [11]. Additionally, research concerning evaluation of correlation between the different QoI layers and basic elements is foreseen.
References

[1] Chen S, Liang Y, Sun S, Kang S, Cheng W and Peng M 2020 Vision, requirements, and
technology trend of 6G: How to tackle the challenges of system coverage, capacity, user
data-rate and movement speed, *IEEE Wireless Communications*, 27 (2), pp 218-228,
doi: 10.1109/MWC.001.1900333

[2] Tomkos I, Klonidis D and Pikasis E, Theodoridis S 2020 Toward the 6G network era:
opportunities and challenges, *IT Professional* 22 (1) pp 34–38, doi: 10.1109/MITP.2019.2963491

[3] Ziegler V and Yrjola S 2020 6G indicators of value and performance, *2nd 6G Wireless Summit (6G SUMMIT)*, Levi, Finland, pp 1-5, doi: 10.1109/6GSUMMIT49458.2020.9083885

[4] Andrade T and Bastos D 2019 Extended reality in IoT scenarios: concepts, applications and
future trends, *5th Experiment International Conference (exp.at’19)*, Funchal, Portugal,
pp 107-112, doi: 10.1109/EXPAT.2019.8876559

[5] Srivastava S 2019 MobileXR: The future of extended reality (AR/VR/MR) - counterpoint
research Counterpoint Research, Available at: https://www.counterpointresearch.com/future-
thended-reality-arvrmr/

[6] Chuah, S H W 2019 Wearable XR-technology: literature review, conceptual framework and
future research directions In *International Journal of Technology Marketing* 13 (3/4), pp
205-259, doi: 10.1504/IJTMKT.2019.104586

[7] Bonetti F, Warnaby G and Quinn L 2018 Augmented reality and virtual reality in physical and
online retailing: a review, synthesis and research agenda, ed T Jung and tom M Dieck
*Augmented Reality and Virtual Reality. Progress in IS.* Springer, Cham.
https://doi.org/10.1007/978-3-319-64027-3_9

[8] Yang H, Yu J, Zo H and Choi M 2016 User acceptance of wearable devices: an extended
perspective of perceived value, *Telematics and Informatics* 33 (2) pp 256–269,
https://doi.org/10.1016/j.tele.2015.08.007

[9] Hamam A and El Saddik A 2012 Evaluating the quality of experience of haptic-based
applications through mathematical modelling, *IEEE International Workshop on Haptic
Audio Visual Environments and Games (HAVE 2012) Proceedings*, Munich, pp 56-61,
doi: 10.1109/HAVE.2012.6374439

[10] Zhang C, Patras P and Haddadi H 2019 Deep learning in mobile and wireless networking: A
survey, *IEEE Communications Surveys & Tutorials*, 21 (3), pp 2224-2287,
doi: 10.1109/COMST.2019.2904897

[11] Lopez-Martín M, Carro B, Lloret J, Egea S, Sanchez-Esguevillas A 2018 Deep learning model
for multimedia quality of experience prediction based on network flow packets, *IEEE
Communications Magazine* 56(9) pp 110–117, doi: 10.1109/MCOM.2018.1701156

Acknowledgments
This work was supported by the National Program “Young Scientists and Postdoctoral Students”,
PMC No577, 17.08.2018, of Ministry of Education and Science of Bulgaria.