Impact of 5G Network Performance on Augmented Reality Application QoE

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***Abstract*—Deployment of 5G mobile communication networks has released the full potential of Internet of Things, enabling emerging interactive technologies such as Augmented Reality and Virtual Reality, as well as their merge. In this paper, we consider the impact of introducing 5G network on the perceptual user experience for an Augmented Reality application – specifically, the educational mobile web-based one as the most promising with this regard. However, it is an extremely demanding application in which various multimedia processing tasks are performed. Therefore, we used appropriate simulations to validate the expectations that 5G network enabling higher data rates and low latency, would significantly improve the application-layer quality of experience, with a mobile web access in particular. These expectations were found to be fulfilled, as, specifically, the required time for the end user to load the tested web-based AR application and required Script, has been drastically reduced with respect to the previous generations of mobile networks.**

Keywords—5G, Augmented Reality (AR), Mobile Web Augmented Reality (MWAR), Internet of Things (IoT)

I. INTRODUCTION

Users ever demand higher data rates, especially in downlink. Multimedia content is getting quite large - e.g., videos that are streamed in ultra-high resolution, which is yet to come to wide use. As demanding large content is needed to be transferred in shortest time possible, it is important to fulfil the requirements of Quality of Service (QoS) and Quality of Experience (QoE), which are usually tested combined to provide a realistic picture of how network performance affects user satisfaction.

Moreover, there are growing needs for better integration of various users and systems through Internet of Things (IoT), which requires faster and more reliable data transfers offered by the Fifth Generation (5G) networks. Features such as scalability, flexibility, efficiency, autonomy, security, and good support of legacy systems with low end-to-end latency, are the advantages that 5G system brings [1-2] beyond the 4G Long Term Evolution (LTE) Advanced systems, which has already offered high bandwidth and advanced services.

International Telecommunication Union (ITU-T) Telecommunication Standardization Sector defined IMT-2000 goals already for 3G mobile networks, with peak speeds of 384 kbps, but introducing High Speed Packet Access, HSPA and HSPA+, for download, in frequency range of 1900-1920 MHz data rates grew up to 14.4 Mbps and 56 Mbps, respectively [3-4].

Furthermore, 4G mobile networks use Orthogonal Frequency Division Multiplex (OFDM) and Multiple-Input Multiple Output (MIMO) with multiple transmit and receive antennas, as well as some advanced techniques of previous generation mobile networks, such as Internet Protocol (IP) based core network. So, as LTE data rate is close to 300 Mbps in downlink [1], whereas with LTE-Advanced (LTE-A) – a bridge between 4G and 5G networks, the data rate is three times larger than with 4G LTE, with other improvements in architecture that include: Carrier Aggregation, Coordinated Multipoint (CoMP), Relay Station, Heterogeneous Network (HetNet) etc. Furthermore, the 5G New Radio (NR) data rates can reach up to 10 Gbps with dramatically reduced transmission delay thanks to Massive MIMO technology extending antenna matrix, coverage, and using pico and femto cells. On other hand, larger frequency range can be used - from 3 to 300 GHz, separated into millimetre-wave band (mmWave) in the range of approximately 30 to 300 GHz, and most commonly used: Sub-6 GHz band [5].

As mentioned, not only that 5G has bring to end user higher rates, but higher spectral efficiency and capacity, with low end-to-end latency which can be less than 10 ms, reducing energy consumption at the same time. Consequently, so far, 5G is expected to interconnect over 80 billion smart devices in the Heterogeneous Network [6], what 4G LTE systems are not capable of [5].

So, we justifiably consider that the proper use of IoT starts with 5G network. The 5G-IoT devices are used in emerging technologies such as Augmented Reality (AR) and Virtual Reality (VR), where AR can be widely used on various, often affordable user devices, which makes it a very effective tool, especially for educational purposes, in real-life scenarios and various environments, even for interactive games.

Accordingly, in this paper we analyse how the emerging 5G-IoT technologies will affect the end-users QoE. With this regard, we consider a simple educational mobile web-based AR application, to explore its QoE dependence on the performance of 5G mobile network, with reference on the performance of previous-generation mobile systems, such as Evolved High-Speed Downlink Packet Access (HSDPA+).

In Section II, we present the mobile-web AR application in 5G experimental environment, to explore the application-level performance in Section III. Conclusions are drawn in Section IV.

II. MOBILE WEB AUGMENTED REALITY IN 5G-IOT

The vision of IoT and enhanced mobile communication has effectively become realistic only in 5G era. Previous-generation networks were not specifically designed to support a variety of connected devices, machines etc., as their primary task was to increase spectral efficiency and enable high bandwidth for applications that required larger data flow. On the contrary, 5G design has taken the mission of developing universal type of communication for emerging technologies such as [7]:

- Enhanced Mobile Broadband (eMBB)
- Ultra-Reliable Low Latency Communications (URLLC)
- Massive Machine Type Communications (mMTC)

In Figure 1, the use cases and features for different technologies enabled by 5G are presented. The eMBB combines with URLLC and mMTC for enabling device to device (D2D), device to everything (D2E) and IoT, as well as Internet of Vehicles (IoV) communication [5].

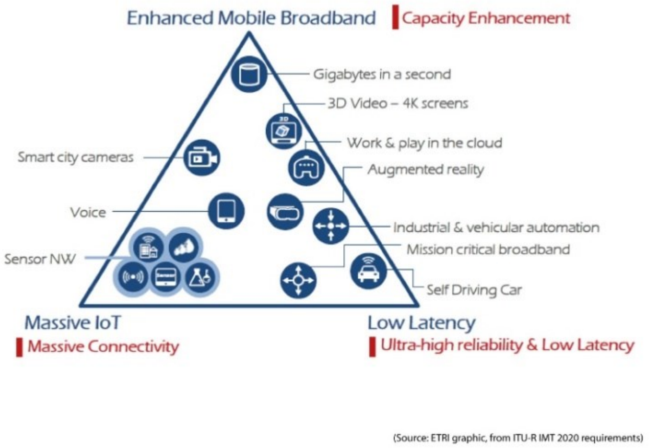

Fig. 1. 5G eMBB vs. mMTC vs. URLLC

The improvements of eMBB arising from 4G to 5G transition include not only advanced broadband access and response to increased user mobility, with higher data rate and latency reduction, but also better integration of various IoT-friendly low-cost devices, which accelerates popularity of AR and VR, as well as of their merge – the mixed reality.

Focusing AR as the technology, note that it has already been in use for a couple of years, but now when combined with 5G, it opens an innovative way of interacting with virtual data that are interpreted into real world perception of the end user, both in terms of price and size of devices used, e.g. smartphones, tablets, phablets, etc.

Various types of generated information include sound, image, text, video, 3D models etc. [5]. The key 5G driver for AR is the enhancement of the overall QoE and delay between an action and response since 5G enables faster flow of information and integration. In this regard, Mobile AR (MAR) is aimed to provide excellent experience over 5G, while the Beyond 5G (B5G), is still in research phase towards 6G. MAR is classified in two categories; hardware-specific and application based [8], where the major drawback of a hardware oriented solution is primarily the cost of additional hardware running on a particular operating system, whereas the application based MAR requires a cross-platform for different applications in which users are required to download and install specific AR applications on their mobile device, for example. So, neither hardware-based nor application-based solution is optimal, especially for applications demanding short response time.

Deployment of web applications in AR technology has opened innovative way of interacting with AR based data. Viewed from the application layer, the HTTP as one of the most common protocols initially aimed for request-response type of data transmission, has also become used in state-of-the-art audio/video streaming. Particularly, the Mobile Web AR (MWAR) has a great potential to promote AR to millions of online users, using the cross-platform user interface from one of the widely used web browsers.

The features of 5G must meet the demands of MWAR, including higher network performance and fast content delivery necessary to drop down latency and Frame Per Second (FPS) for computation-intensive and delay-sensitive applications [8]. Moreover, applying the principle of edge computing, where data are processed by the server nearest to the point of data origin, latency and response time can be drastically decreased. So, considering growth of IoT devices and cloud data that they are creating, applying edge computing is unavoidable, combined with 5G networks.

As an example, in Figure 2, communication between two different MAR applications is presented, where the client side contains six users overall, divided into two groups that access the Mobile Edge Computing (MEC) cloud at the 5G base station by their mobile devices' (Android or iOS) cameras or touchscreens, over the URL pre-defined for each AR application. The users of the same group achieve improved latency and FPS because of the benefits of 5G D2D communication. The most relevant QoS parameter - data rate determines the performance and so impacts the overall QoE [8].

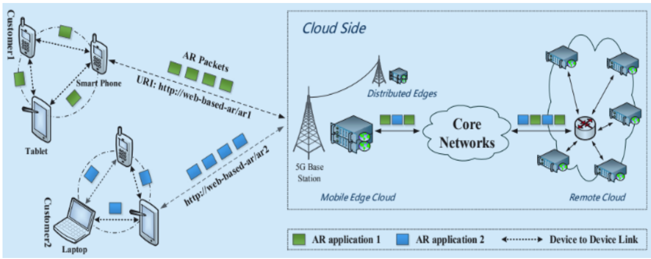

Fig. 2. 5G Exemplar architecture for two web-based MAR applications [8]

III. Performance Evaluation of Mobile Web AR Application

Creating AR experience is challenging since combining and synchronizing the real world and motions of the user with a digital world requires a massive amount of graphical rendering processes. AR requires stringent network conditions such as low latency, high reliability, and high bandwidth, which can all be fulfilled by 5G wireless networks.

In the following, the performance of a free web-based AR application is to be evaluated by simulating various generations of mobile networks, ranging from 3G mobile networks (HSDPA+ in particular) all the way up to the mmWave bands of 5G. ViewToo Face Mask Guide is the selected AR application developed by the Italian company Viewtoo [9] after realizing that many people were unsure how to wear their face masks correctly for better protection in the pandemic of COVID-19.

This application was chosen because of its simplicity, design, and relevance during pandemic time. The AR experience places a mask onto the user and then guides him through a series of instructions on its proper use, from placing it on the face, to disposing it. It also warns against taking the mask off for phone conversation, or for keeping it lowered under the chin. The application provides a visual and virtual way of showing how to use the items [10], and was built using Zappar Web-AR [11].

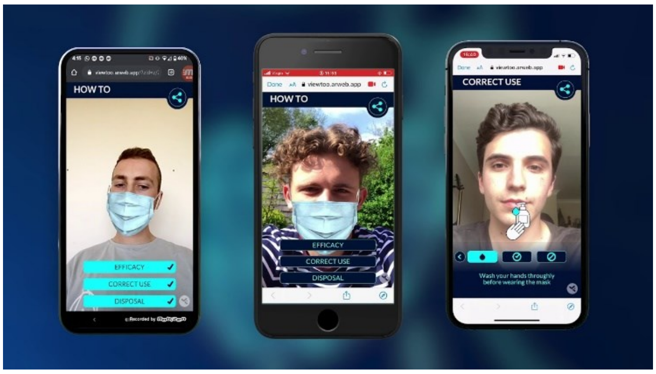

Fig. 3. Showcase of ViewToo Face Mask Guide on the mobile web browser [10]

To check how the data rate affects the application performance, Chrome Developer Tools (DevTools) was used as a set of web developer tools built directly into the Google Chrome browser. It can help edit pages on-the-fly and diagnose problems quickly. One of the features that Chrome DevTools offers is also the Network panel from which it can be checked whether the resources were uploaded and downloaded at all, inspect properties of HTTP headers, content, protocol data unit (PDU) size and so on, but it can also simulate a slower network connection by throttling the page.

For this analysis, we considered the load time for the application and the FaceFinder (FF) Script which is crucial with this regard, as the load time is the elapsed time between the user submitting an URL, and the entire page available on the browser for the user. The lower the load time, the better the QoE quality of experience, as the load time to the large extent influences the user satisfaction [12]. FaceFinder is a function from the Web-AR library which finds the face of the user in the camera feed and places the mask on the face.

The network performance characteristics are tested in a real-life environment delivered by Croatian network operators, where the data rates for 5G are presented in Sub-6 GHz and mmWave bands, as it is presented in Table I.

All enlisted networks are considered to be tested in perfect conditions, and the upload rate is considered to be irrelevant for this simulation. The simulations were performed on the Croatian Academic and Research Network (CARNET), at the hub of the University of Dubrovnik, with stable connection, continuity of rate and latency.

TABLE I. DATA RATES AND LATENCY USED FOR ANALYSIS

Mobile network type	Download (MB/s)	Upload (MB/s)	Latency (ms)
HSDPA+	14	3.4	350
4G LTE	66	9.1	80
4G LTE-A	244	15	45
5G Sub-6 GHz	327	22	10
5G mmWave	>1000	33	10

We conducted our tests in five iterations for each network data rate. Between the iterations, cache memory was erased, and caching was disabled to make sure it does not affect the load time [13]. The load time for data and FF Script time for each iteration are presented in Table II.

For data credibility reasons, the diagram in Figure 4 represents the average results for each iteration of the application load and FF Script times.

From the obtained results it is evident that 4G LTE exhibits better results than HSDPA+, where for the latter the worst scenario was adopted, which occurs if the user equipment is in poor coverage region, where it is still possible to access mobile data and application.

The application load time and the FF Script time for 4G LTE and HSDPA+ are improved by 4.3 times and 3.5 times, respectively. However, significantly lower FPS in HSDPA+ was experienced due to not only lower data rate, but also due to quite large latency.

By evolving from 4G LTE to 4G LTE-A, the latency has dropped almost by 2 times, whereas the data rate increased by 3.6 times, where the time to load the application and FF Script was shortened approximately two times.

Regarding 5G in the Sub-6 GHz band, the data rates improved by 1.3 times in comparison with 4G LTE-A, and the latency dropped from 45 ms to 10 ms, respectively. The application loaded two times faster, much alike as the FF Script which loaded 1.8 times faster.

When entering the mmWave 5G band, the data rate was in the range above a Gigabit per second. It has come out that still there is a reduction of load time, just for FF Script which is now 1.5 times faster as the application load time remained the same as before, because what matters now are the hardware capabilities of the processing device and its response time.

Finally, it can be stated that the values coming out of our simulations verify the performance figures for 5G mobile networks, which exhibit significant improvements as well as less design limitations with regard to the equivalent 3G and 4G (LTE) networks.

TABLE II. SIMULATION RESULTS FOR EACH ITERATION

Mobile network type	1st Iteration		2nd Iteration		3rd Iteration		4th Iteration		5 th Iteration	
	Load time (ms)	FF Script (ms)	Load time (ms)	FF Script (ms)	Load time (ms)	FF Script (ms)	Load time (ms)	FF Script (ms)	Load time (ms)	FF Script (ms)
HSDPA+	2350	1040	230	1020	2360	1020	2540	1020	2340	1020
4G LTE	549	240	566	235	552	261	554	234	563	373
4G LTE-A	364	126	240	138	235	145	452	167	210	96
5G Sub-6 GHz	185	57	167	68	207	108	34	63	134	61
5G mmWave	125	42	139	57	119	48	178	39	129	40

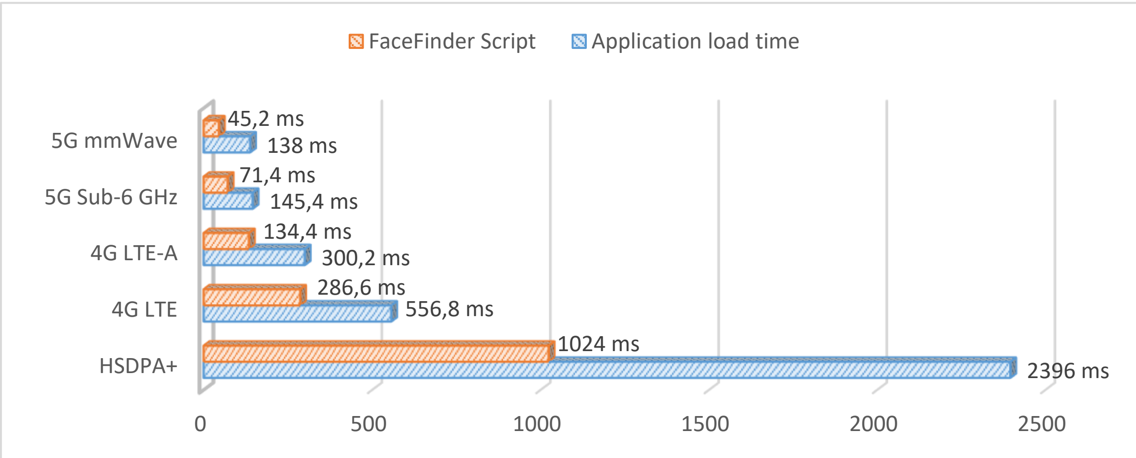

Fig. 4. Average application vs. FaceFinder Script load time

IV. CONCLUSION

The evolution of 5G-IoT devices has reinforced development of emerging applications such as e.g. Augmented Reality, specifically the mobile web AR. This provides a pervasive mobile AR experience to users thanks to wide deployments of the web as a lightweight service provisioning cross-platform, whereas hardware and application - based mobile AR both lack flexibility and require additional downloading and installation in advance. With benefits of 5G mobile networks, most of requirements for good QoE over a browser for MAR, were found to be fulfilled and significantly enhanced regarding the previous generations of mobile networks. Specifically, for the end user, the required time to load the tested web-based AR application and required Scripts has been drastically reduced. Future idea is to extend research to more complex applications and evaluate how they will affect on users overall QoE, taking into an account more segments of application.

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