5G TECHNOLOGY AND ITS APPLICATION TO E-LEARNING

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Abstract

Currently, there is a great deal of interest in the advent of 5G technologies, due to the perspectives they open up in various fields, among which e-learning. In this paper, an experience of online learning is described, concerning an online bachelor degree of the Università degli Studi di Milano delivered with currently available technology. An investigation is conducted about whether the services offered to learners might improve with the forthcoming 5G technology. To this aim, the characteristics of main multimedia applications are reviewed; the services and performance theoretically supplied by 5G are derived from a literature analysis; a numerical evaluation is conducted basing both on that analysis and on simulation results, in comparison with LTE.

Keywords: 5G, e-learning, interactive sessions, video lectures.

1 INTRODUCTION

A technology that, in the near future, is likely to change our lives is the latest generation of wireless mobile communications, known as 5G. It introduces significant improvements with respect to current networking technologies in terms of a larger bandwidth, a more reliable service, very low latencies and a higher density of devices.

The questions we want to address in this paper are: can 5G be profitably applied to already existing e-learning initiatives? What didactic services, currently hard or impossible to implement, will become potentially available to e-learners?

In academic year 2004/05, the University of Milan (Italy) started offering also online an undergraduate, three-year bachelor degree on Security of Computer Systems and Networks (from here on called SSRI, its Italian acronym), activated the previous year in the traditional fashion for students participating in presence to lectures and lab activities. In addition to the positive aspects that are determining the success of SSRI - and other similar initiatives - among students, there are a number of limitations due to current network technologies, such as the difficulty in organizing synchronous interactive educational sessions or sharing high-quality materials. In this context, the availability of 5G technology can offer interesting options for overcoming the mentioned limits, as we will explain in the following.

The standard 5G documentation approved on mid 2018, and the first deployed trials, allow to characterize the services supplied to 5G users, and to estimate the performance achievable for applications such as two-way real-time conferencing, high-quality video streaming, and immersive experiences. Those applications and performances may support innovative services for e-learning such as virtual lessons where learners can interact in real-time with the teacher with questions and remarks, and the experience of a realistic laboratory exercise as in presence through, e.g., virtual reality platforms.

The paper will concentrate, from one side, on the performances offered by 5G and, from the other side, on requirements for a mobile, high-quality interaction and access to video materials, to identify where 5G should be firstly adopted as soon as it will become available. In detail, we describe the infrastructure used for the implementation of the SSRI online course. We analyze the quality of learners experience with the SSRI platform and their feedbacks. We present some numerical evaluations about the quality of service available to users with the 5G technology, and we use the achieved results to delimit the feasibility of innovative services for SSRI and the number of students who can benefit from these services, in comparison with the existing situation.

The paper is organized as follows: in Section 2, the experience with SSRI is reported. Section 3 summarizes the network requirements of different video streaming applications. In Section 4, the characteristics of 5G technology are discussed. Section 5 reports some numerical evaluation

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highlighting the extent to which 5G is able to support the applications discussed in Section 3. Section 6 concludes the work.

2 EXPERIENCE WITH SSRI

As already outlined, the online version of SSRI required a significant re-design process with respect to the traditional, face-to-face one. Such a process has been supported by consultants from Isvor Knowledge System (an Italian company specialized in the production of e-learning courses) that worked together with the university staff of CTU, the e-Learning Centre of the University of Milan, in defining the teaching model and the technological architecture of the project (see e.g. [1], [2], [3] and [4]). The resulting structure of SSRI online can be summarized as follows:

- each online course is structured in modules corresponding to the various topics. Each module is composed of didactical units, associated with the various aspects of the topic and constituted by different activities: lectures, exercises, tests;
- all teaching material is available to students on the CTU web platform, which provides also forum discussions among students and tutors;
- students progress is monitored by tracking their activities and the results of the tests associated with each online lecture;
- online activities are coupled with face-to-face meetings with teachers, planned only for course introduction, midterm tests and final exam. All other interactions with students are constituted by asynchronous communications, mainly through forums and (very seldom) via e-mails.

The teaching material is constituted by video-lectures, obtained by capturing the teacher's PC desktop (used mainly for presenting sequences of slides) synchronized with the explanation given by the teacher's voice. It should be noted that the average duration of each video-lecture is about one fourth of the corresponding classroom lecture, to facilitate the learning activity of online students allowing them to concentrate for a short time on the video message and eventually to iterate the procedure.

Video-lectures are offered to students through the e-learning platform managed by CTU, and can be followed when the student is connected to the platform as well as by downloading and playing them when the student is offline.

Even if SSRI online proved to be a very successful initiative in terms of number of enrolled students, results in exams, final graduation grades (see e.g. [5]), it suffers a significant limitation: the possibility of organizing synchronous interactive sessions with a student population mainly constituted by already employed people, having difficulties in connecting through a PC during working hours.

To overcome this limitation, it would be useful to be able to reach students through mobile devices and to organizing activities like:

- broadcasting high quality video from the teacher to a population of around 100 students, simultaneously connected;
- driving the above population into some immersive experience, as, for instance, the virtual access to a huge computer center where the teacher can show how to configure the various devices;
- distributing to the above population a high-quality video captured by single students, in order, e.g., to share and discuss the lab work carried on by each student in response to teacher's stimuli.

3 PRELIMINARIES ON VIDEO STREAMING

In this section, an analysis is presented of the typical requirements of multimedia applications, regardless of 5G networks.

Several formats have been standardized for video streaming, depending on the image definition supplied to users; Table 1 reports a summary of the main formats in use. The 360p format is the base resolution adopted by, e.g., YouTube; it is adequate also for low-bandwidth connections and small devices. The 720p format is also known as *half-HD,* while the 1080p format is known as *full-HD*; both may be encoded with either 24 or 60 frame-per-seconds (*fps*). Currently, the highest video quality is obtained through the 4K format (*ultra-HD*), that may also supply 360° images for immersive experiences.

Table 1. Standard video formats.

	360p	720p	1080p	4K
Size (pixels)	640 x 360	1280 x 720	1920 x 1080	3840 x 2160

Considering the data compression and the fps rate, different requirements are posed to the network in terms of bitrate in order to diffuse those video formats. Additional features are required for supplying a good Quality of Experience (QoE) to users, in terms of both latency and reliability, i.e. the percentage of messages delivered to the destinations. Table 2 summarizes the bandwidth, latency, and reliability requested by different applications and data traffics. As far as latency is concerned, while one-way streaming applications tolerate delays of a few seconds, two-way conferencing applications have a more stringent requirement in the order of around 100 ms in order to supply high QoE to users [6]. 4G cellular telephony still might meet the characteristics of high-quality (4K) video streaming, such as those supplied by some media-service providers [7], although at only one destination at a time. By contrast, applications involving Augmented Reality (AR) and Virtual Reality (VR) significantly push forward these requirements [8][9][10]: in order to supply a realistic and immersive experience to users, ultra-low latencies of less than 10 ms are needed; for retina-experience video, the requested bandwidth may increase up to some Gbps. For both two-way interactive conferences and AR/VR, reliability must be not less than 99%.

Table 2. Summary of needed network performances for multimedia applications.

	Bandwidth	Latency	Reliability
Standard A/V streaming	≤ 3 Mbps	4 – 5 s	≥ 95%
HD video streaming	4-8 Mbps	4 – 5 s	≥ 95%
3D HD video streaming	9 Mbps	4 – 5 s	≥ 95%
4K video streaming	25 Mbps	4 – 5 s	≥ 95%
Interactive real-time conferencing	≥ 2 Mbps	~ 100 ms	99% – 99.5%
AR	100 Mbps – 5 Gbps	1 ms	99% – 99.5%
VR (interactive)	100 Mbps – 2.35 Gbps	10-30 ms	99% – 99.5%

4 CHARACTERISTICS OF 5G NETWORKS

The standard document for 5G technology (3GPP 2019) has been published in March 2018 by 3GPP and officially approved in the Plenary Meeting in June 2018. 5G technology promises to be able to support a number of both traditional and novel applications, such as device-to-device communication and Internet of Things (IoT).

For the goals of this paper, the investigation is carried out about 5G functionalities and performances that may facilitate the implementation of advanced e-learning services. In particular, the support 5G may give to audio and video data exchange is discussed, as well as its capabilities of facilitating data sharing through the formation of extemporary classrooms anywhere relying on users' devices only. To this purpose, an analysis is presented of existing – mainly European – 5G trials, in order to assess the feasibility of e-learning platforms leveraging this technology.

Considering how recent the standardization of 5G is, determining to what extent 5G will be able to fulfill the requirements in Table 2 is not easy. As far as services are concerned, 5G includes both an ultra-reliable low-latency communications (URLLC) service, and an enhanced mobile broadband (eMBB) service [11]. Deliverable D1.1 of the 5G-EVE consortium [12] defines the characteristics of these services. URLLC aims at providing latencies no greater than 50 ms and reliability of more than 99.9% [13]; it is intended for use mainly with industrial and vehicular applications in order to guarantee prompt delivery of emergency notifications. Under these points of view, it also fits the requirements of AR and VR applications; though, it will be able to provide a data rate of up to 10 Mbps. By contrast, eMBB aims at providing ultra-high bitrate so as to address the needs of users accessing multimedia content, ranging from real-time video streaming to online gaming with 3D 4K video; in particular, it should provide a peak data rate of up to 20 Gbps for the base station, with minimum 100 Mbps guaranteed to users. This service seems best suitable for e-learning applications. In the same document, the goal for Media & Entertainment applications is TV service for mobile users with bitrates of 100-200 Mbps (with peaks of up to 250 Mbps in downlink) and latency lower than 100 ms. An aspect that is still under investigation is how the different services will coexist; their combination seems impossible, since different mechanisms are adopted to implement each of them [14]. Coexistence of URLLC and eMBB might delay network access for eMBB traffic, thus affecting its performance; this will depend on the mix of different traffics in real infrastructures.

An interesting characteristic of 5G is its multi-RAT (multi-Radio Access Technology) nature. This means that 5G will be able to cooperate with different technologies such as 4G cellular telephony, but also with Bluetooth or WiFi. Both Bluetooth and WiFi are license-free technologies, which however might provide limited bandwidths: Bluetooth 5 supplies a bitrate around 2 Mbps, while WiFi – in version 802.11ac – can reach, in real deployments, up to ~200 Mbps. An alternative incoming possibility is that of using LTE Direct: it is an addition to 4G LTE technology [15] that allows to offload base stations by supporting direct device-to-device communications between devices in the same cell. In 2015, Deutsche Telekom deployed a first trial of LTE Direct, validating the feasibility of the technology [9]. LTE Direct supplies a higher radio range than WiFi also in urban areas, it supports quite high mobility (up to 30 Km/h), but provides bitrates of the order of 3.5 Mbps uplink and 13 Mbps downlink.

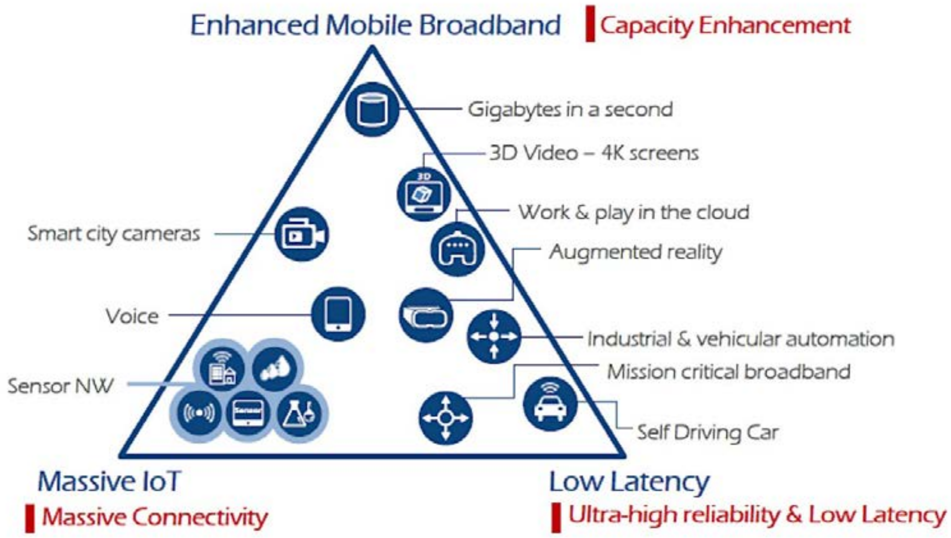


Figure 1. The triangle of 5G applications (source: ETRI graphic, from ITU-R IMT 2020 requirements).

With these premises, a number of scenarios currently not implementable will be achievable in the future, through an accurate combination of radio technologies and services. Fig. 1 outlines some possible applications, by arranging them along the axes that link the peculiar features of 5G systems: 1. capacity enhancement, 2. ultra-high reliability & low latency, and 3. the ability of connecting an ultra-high number of devices.

In [16] these scenarios are described as follows:

- Amazingly fast – Users can obtain very high data rates with instantaneous connectivity and low latency. This is crucial for multi-layer applications based on multiple high-quality media streams;
- Great service in a crowd – Currently, connectivity is limited when many users share the same area (e.g., stadiums, concert halls, etc.), but in the future also crowded places will permit a satisfactory experience;
- Ubiquitous things communicating – The mix of IoT and human-centric communications tends to have different needs, and the 5G technology will efficiently handle these new requirements;
- Best experience follows you – Even when users are on the move (e.g., traveling by car or commuting), a high quality of service will be guaranteed;

- Super real-time and reliable connections – Future wireless systems will support new applications that take full advantage of very high reliability and low latency, thus allowing real-time fruition (e.g., augmented/virtual reality) as well as control (e.g., self-driving vehicles and industrial automation).

4.1 5G state-of-the-art and trials

In order to assess the characteristics of 5G networks in real or realistic environments, a number of experiments are ongoing. On December 2018, the Italian Inter-University Consortium for Telecommunications (CNIT) promoted a conference involving information technology companies, telecommunication companies and representatives of the European Commission [17]. The talk by Enrico Salvatori of Qualcomm supplied a measure of bandwidth of 1.4 Gbps in a testbed in San Francisco. According to Peter Stuckmann of the European Commission, the 26 GHz frequency band will be reserved for fixed wireless access with a bitrate of up to 10 Gbps, while the 3.6 GHz frequency band will be used for urban mobile access guaranteeing users a data rate of 1-3 Gbps.

For the Bari-Matera installation in Italy, the 5G-PPP consortium [18] reports an obtained bitrate of around 3 Gbps with a latency of about 2 ms [19]. In this case – as mentioned above – 5G is mixed with the LTE technology [20]; the migration towards pure 5G is scheduled for mid-2019.

The European 5G Observatory [21] provides data from around 180 trials and experiments. Data are contradictory, as noticed in the site, with bandwidths variable between 1.7 Gbps and 25 Gbps; this likely depends on whether measurements are taken in a real urban infrastructure, or rather are conducted in a laboratory. From the data analysis, it seems that the most realistic measures have achieved 700 Mbps to 1 Gbps data rate in download; this test was conducted in a Finnish urban area, hence with a reasonable user density. Over all experiments, peak data rates between 250 Mbps and 70 Gbps have been achieved, with an average of 1 to 4.5 Gbps for user devices, and latencies < 5 ms. However, it is worth noticing that peak data rates have been obtained in small testbeds (e.g., involving a small number of users and one antenna), possibly in laboratory, thus their applicability is limited.

Summarizing the above considerations, we may say that the existing realistic trials are able to provide a 700 Mbps to 1 Gbps (or more) bitrate on user's devices, with low latencies, also of the order of a few milliseconds. According to Table 2, this performance may satisfactorily support the requirements of all applications including AR/VR, thus making 5G the elective technology for the deployment of innovative e-learning services such as those discussed later.

However, a couple of remarks must be discussed. The analyzed trial results have been obtained with currently existing infrastructures, which represent the first prototype implementations of the 5G standard, possibly built from existing 4G infrastructures of providers that are gradually trying to commute to 5G. Better results will likely be obtained in future years with the improvement of both hardware and software components. Moreover, the performance really observed by users will strongly depend on the mix of traffics (asking different services) that will be injected into the networks, and on how they will compete for network resources.

5 5G FOR SSRI: ARE PROBLEMS SOLVED?

In this section, some numerical results and evaluations are supplied in order to highlight the evolution that 5G technology may bring to e-learning with respect to currently available technologies. We conclude the section with a summary of our findings.

5.1 Preliminary considerations

When projecting video-streaming applications on a network, an aspect to be considered is the transport protocol to use. The most recently proposed protocol is VSF TR-03 [22], standardized in 2018 as SMPTE ST 2110-20. This protocol minimizes the control information added to the video data, and it asks to use UDP messages not larger than 1440 byte and a clock rate of 90 KHz. According to this standard, the source settings in terms of both bitrate and packet rate are determined depending on the video format. The *Kush Gauge* rule of thumb to compute the bitrate is:

$$Bitrate = frame\ width \times frame\ height \times frame\ rate \times motion\ factor \times 0.07$$

where the motion factor accounts for the amount of movements in the video.

Yet, this is not the global generated traffic. Three addressing modes exist to diffuse information in Internet, namely unicast, multicast, and broadcast. *Broadcast* implies that a data is contemporarily diffused to all devices in a certain network, which in the case of wireless networks comes at no cost since the radio media is intrinsically broadcast. Yet, in e-learning scenarios, not all devices in a certain wireless cell necessarily belong to learners involved in the same class; hence, broadcasting is not applicable. *Multicast* means that a group of users is identified with a particular network address, and multicast protocols are used in the network in order to limit the message replication to the different destinations. Unfortunately, multicast is seldom supplied by Internet Service Providers (ISPs), and only on demand of clients. It requires an a-priori setup of both the network and the involved devices, thus it is not suitable to form an extemporary classroom where learners dynamically request access to the content stored in a remote server. Hence, unicast is the only viable solution, but it imposes that the content source replicates *one copy of data* for each destination. As a consequence, both *(i)* the available network bitrate must be shared among the replicas of a certain content addresses to different destinations; *(ii)* queues may form on both the source and network devices, consequently the reception of data is slowed down. As an example, Table 3 shows the overall bitrate that a network is asked to provide as a function of different video formats – according to the Kush gauge with low motion factor (1) – and number of destinations.

Table 3. Required bitrate for different number of users..

	1 user	**20 users**	**50 users**	**100 users**
360p	387 Kbps	7.74 Mbps	19.35 Mbps	38.71 Mbps
720p	1.55 Mbps	30.97 Mbps	77.4 Mbps	154.8 Mbps
1080p	3.48 Mbps	69.7 Mbps	174.2 Mbps	348.4 Mbps
4K	13.9 Mbps	278.7 Mbps	696.7 Mbps	1.39 Gbps

For many recipients, there is the risk that some data are dropped due to memory exhaustion. Finally, it is worth considering that not the whole available bandwidth can be used for data. In fact, part of it must be used either for control messages needed for the proper network operations, or for control information added to data for proper management. Further discussion on these aspects is presented in Section 5.2.

5.2 Video streaming performance

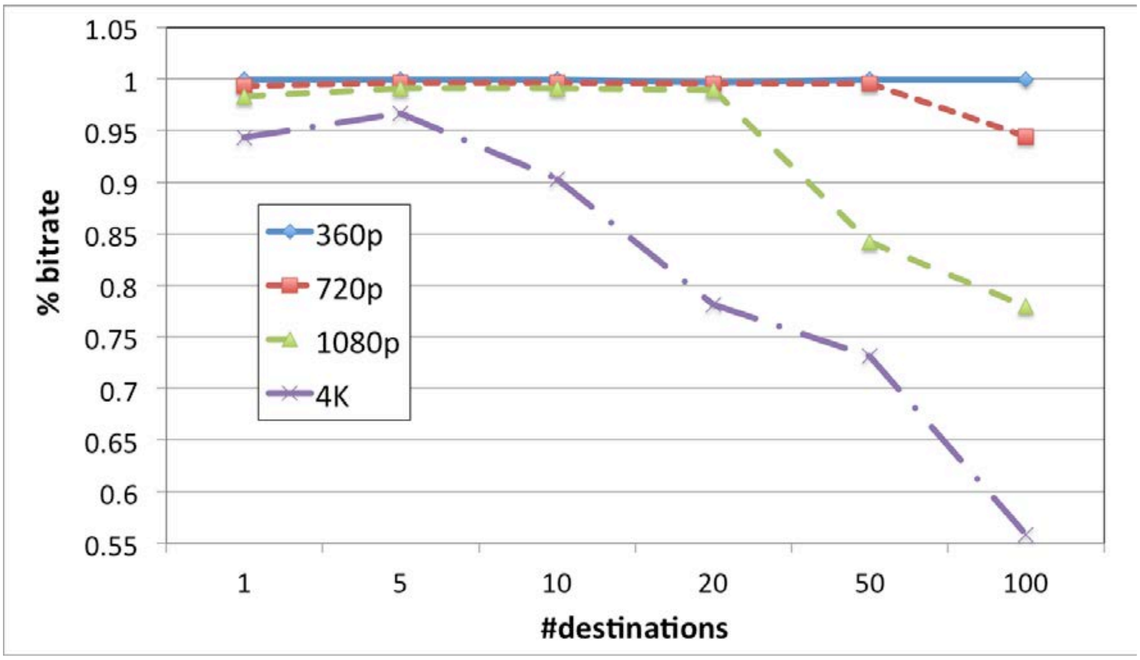
In this section, an estimation is presented of the expected 5G performance for video streaming in comparison with 4G LTE cellular telephony technology, basing also on performance measurements for LTE using simulation techniques. As a simulator, the OMNET++ Discrete Event Simulator [23] version 5.1.1 has been used, jointly with its INET and SimuLTE frameworks.

At the time of writing, LTE is the best available wireless technology, and – according to the standard specification – it should provide gross bitrates (transporting both data and control information) of the order of 150 Mbps downlink and 75 Mbps uplink. As a consequence, it is evident from Table 3 that LTE satisfies the requirements of 360p videos for up to around 200 contemporary users, but for not more than 50-60 users in the case of 720p videos, and for less than 30 users for 1080p videos. AR/VR content download might be supplied to at most one user per cell at a time.

LTE simulations were conducted in a network formed by a server in Internet that transfers a video of variable format to a number of users ranging from 1 to 100, all in the cell of a LTE antenna. According to the VSF TR-03 standard, frames are broken in message of 1440 byte at most.

The plots in Fig. 2 show *(a)* the performance in terms of average bitrate at the destinations, and *(b)* the latency for the transfer of 1 MB file. The bitrate is represented as a percentage of the required bitrate according to Table 3. In the 720p case with 100 users, the bitrate refers to just the users who received at least 1 message, which are 83. Similarly, with 1080p and 4K, some destinations did not receive any data, while others observed bitrates lower than expected. These results emphasize the queuing problem described before: the data to the missing destinations were dropped. As far as latency is concerned, some bars in Fig. 2 are not visible in the plot as they refer to values around 5 ms. While with a 360p video the observed latency is always less than 5 ms, with a 720p video it grows to 5.2 ms with 50 users, and with 100 users the average latency is 2.22 s, which is inadequate for two-way interactive conferences and AR/VR applications according to Table 2.

(a)



(b)

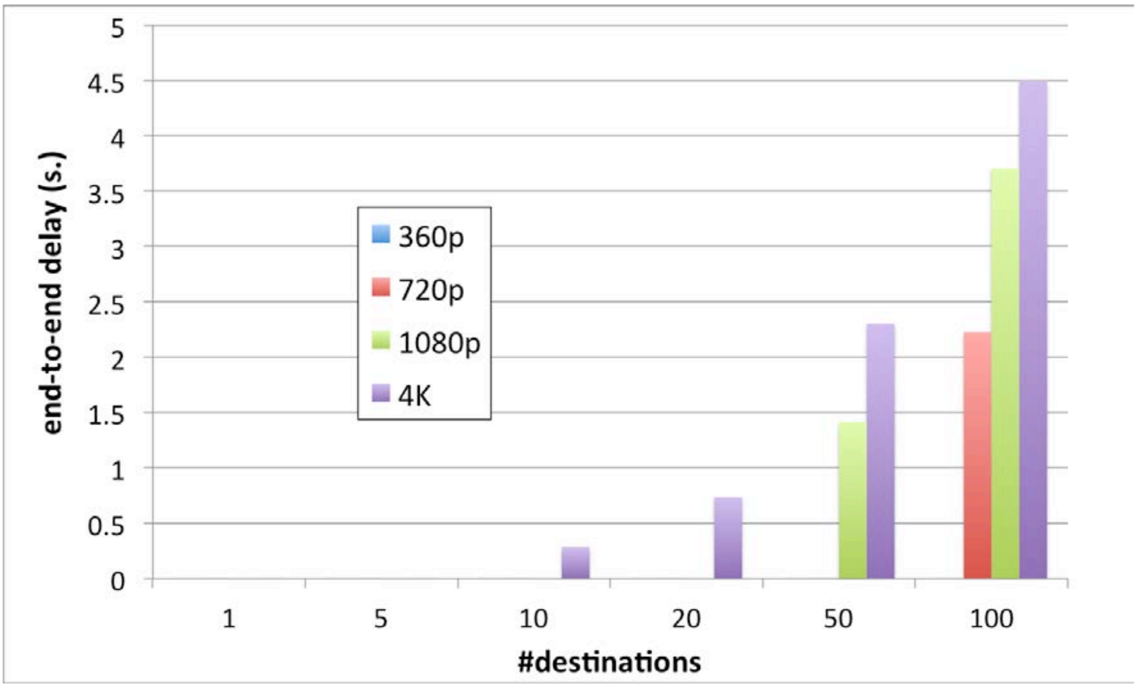


Figure 2. (a) Percentage of expected bitrate and (b) latency results for LTE.

5.3 Online teaching and learning perspectives with 5G

The lessons learnt from the simulation results obtained with the model of LTE allow deriving some estimation about the expected behaviour of 5G.

According to the analysis of existing 5G testbeds, such a technology should provide a bitrate of 1 to 3 Gbps in download, and around 100 Mbps in upload. This is in line with the requirements for advanced international mobile telecommunications [24], which though distinguish between 1 Gbps download bitrate for (almost) stationary users, and 100 Mbps download bitrate for highly mobile users. Let B_{5G} = *1Gbps* be the expected available bitrate. With such a bitrate, video streaming is possible with 5G for all video formats up to 1080p and for more than 100 *contemporary* learners asking access to the same content. As far as the 4K format is concerned, 5G should support up to 50-60 contemporary users. Yet, AR/VR content distribution seems still a challenge for 5G: the poorest data encoding for those applications requests a data transfer bitrate of around 100 Mbps. As a consequence, apparently less than 10 learners might access AR/VR content, and experience sharing is thus hindered.

As far as queue usage is concerned, 5G solves this problem also, thus increasing reliability. In fact, with 1Gbps bitrate, a 1440 byte data message is sent every 11.52 μs, which is far smaller than the message interval in 4K, equal to 826.7 μs.

If message queues do not form, then reliability is guaranteed, and latency as well, since messages do not have to wait for transmission. Hence, we expect that in 5G, in the absence of queues and with a transmission delay equal to 11.52 μs, latency is not greater than a few milliseconds. As mentioned before, queuing problems can occur in 5G with a high number of learners contemporarily accessing either a 4K or an AR/VR content; latency depends on the number of messages in the queue, while reliability depends on the memory maximum size.

It is worth to emphasizing that, if learners are distributed across different wireless cells, the bitrate B_{5G} is available to every subset of users in a certain cell, thus reducing contention and increasing the number of overall users that may be served in parallel.

A different aspect concerns the possibility for teachers and learners of producing content during a lesson and then upload it on a server, e.g. for off-line sharing. In this case, 5G might be not much different from LTE: the gross bitrate for the former should be around 100 Mbps, while for the latter 75 Mbps. In case 1080p videos are considered, up to 20 users may simultaneously share uplink capacity in case of LTE, and 28 in case of 5G. With these numbers, also *data implosion* at the server – due to contemporary reception of large amounts of data – should be manageable, and message loss at the server should be avoided.

6 CONCLUSIONS

In this paper, the experience of online learning is described concerning the online SSRI course of the University of Milan. An investigation is conducted about whether the service offered to learners might improve with the forthcoming 5G technology. To this aim, the characteristics of main multimedia applications are reviewed; the services and performance theoretically supplied by 5G are derived from a literature analysis; a numerical evaluation is conducted basing both on that analysis and on simulation results, in comparison with LTE.

The investigation reveals that 5G technology is potentially able to provide a better service, in terms of quality of the shared content, to a greater number of *contemporary* learners, with virtually no loss of data and very low latencies in receiving the content. This aspect is particularly critical when real-time features are intrinsically required by the educational goals, such as in remote music lessons or network distributed musical performances [25].

Contemporaneity opens the perspective of easily deploying extemporary classrooms, thus allowing learning experiences to take place not only in institutional places such as universities or schools [26]. These characteristics also facilitate parallelism among learners diffused on a territory, which might be the case of worker students for whom remote learning is more adequate. Furthermore, the very low latencies estimated for 5G support two-way interactivity, thus allowing the implementation of blended synchronous learning.

Limits to these outlooks seem represented by both user's mobility and immersive experiences. As far as the former aspect is concerned, possibly worse performance will be perceived by highly mobile users, such as workers trying to take a lesson while commuting. Regarding the latter, the very high demands of AR/VR applications might be critical for 5G technology as well [27], allowing either a low quality of experience, or the sharing of the experience amongst a low number of simultaneous learners in a given cell.

The presented evaluation was conducted with a conservative estimation of the bandwidth provided by 5G according to current realistic trials. Results will have to be scaled to the bitrates actually available in wireless cells once 5G antennas are deployed and commonly used.

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