Perceived Quality of Service and Content-based Bandwidth Management in e/m-Learning Smart Environments for the Cultural Heritage

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Abstract: Smart Applications for the Cultural Heritage are playing an increasingly fundamental role in several fields, ranging from tourism to home entertainment. E/m-Learning systems are also involved, since advanced contents from the Cultural Heritage can be used in History of Art lessons. For instance, teachers can decide to make students enjoy HQ images or videos of masterpieces, accessed from the Internet. In this context, several problems must be considered, among which an appropriate fruition of such data. In this paper, two specific issues are taken into account: firstly, the so called Perceived Quality of Service (PQoS) in case of visual information; secondly, the case is discussed of high-bandwidth demanding contents accessed in real-time, such as HQ streaming videos. An early architecture is finally proposed for the dynamic management of bandwidth release on the basis of content size and duration.

1 INTRODUCTION

The increasing availability of rich multimedia contents from the Internet is playing an important role in several services. Consider for instance smart applications for the Cultural Heritage, currently used in many fields, such as tourism and home entertainment. Such applications are full of interesting contents, that can be used in e/m-Learning activities, for instance in the field of History of Art. This case is here discussed, and the following scenario considered: a teacher and his or her students use an e/m-Learning system, where contents from the Cultural Heritage are adopted, such as HQ images or videos available on the Internet. Teachers choose which visual information must be accessed; students follow lessons from home or outside, using: (1) heterogeneous devices, such as desktops, laptops, tablets and smartphones, and (2) different network access connections, such as a WiFi from a 100 Mbps wired, a 20 Mbps DSL or GPRS (2 Mbps, used in several smartphones or tablets if no WiFi is at disposal).

The learning goal is to enjoy rich and detailed contents properly, for instance in History of Art lessons. In this case, HQ images or videos need to be accurately displayed. The problem is particularly important of visual quality, which depends on several factors, such as screen resolution and network access speed, especially if high-bandwidth demanding contents are accessed in real-time.

Contents are meant to be shown to a class, but each student accesses the system using his or her device and network access technology, which can both vary over time depending on where and how students log on to the system. In consequence, the possibility to access the requested visual information properly or not must be checked for each individual, according to distinct situations and learning tasks.

This paper focuses on two specific and related aspects concerning quality of advanced visual contents from the Cultural Heritage and their use in smart education environments (images and videos).

First, the concept is investigated of “Perceived Quality of Service” (PQoS) in visual environments, and a representation is proposed of the steps between reality representation and perception. The considerations made refer to every kind of visual information, but are particularly important in case of contents from the Cultural Heritage. The second aspect faced refers to lessons involving high bandwidth-demanding contents, such as HD streaming virtual visits to museums, where the bottleneck is data dimension with respect to network

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access speed. An early architecture is consequently proposed for the dynamic management of bandwidth release on the basis of content size and duration.

As an introduction, some considerations are made about PQoS, quality of transmission and display, and a representation proposed of the main steps among the object represented and its final perception. As for PQoS, the term "Quality of Service" (QoS) (Bai, B., 2010, Ganesh Babu, T.V.J., 2001, Montazeri, S., 2008) is rapidly evolving into the concept of PQoS. In Smart Environments, PQoS (Suffer, D., 2009, Vankeirsbilck, B., 2013, Zhengyong, F., 2013) depends strongly on the user, senses involved, kind of application, architectures, advanced interfaces and technologies applied, concerning both devices and kind of network access. This is the link between the first and second aspect discussed: quality of perception in visual smart environments strongly depends on technical factors. Quality of image and video transmission, in particular, are related to both bandwidth required and access technologies, and the following considerations can be made. First, Smart Environments are increasingly being enjoyed through mobile devices and wireless networks; second, contents from the Cultural Heritage are growing richer and increasingly bandwidth-demanding. The network and its performance, thus, are fundamental. The same applies to device quality, such as screen size and resolution.

Fig. 1 represents the layers among every kind of visual object and its final perception. In more detail, the factors defining quality of service and its perception in smart visual applications, can be classified as: (i) actual contents and their representation; (ii) smart application architecture; (iii) smart application interface; (iv) network architecture; (v) user's network access technology; (vi) user's device; (vii) user's personal perception. The schema in Fig. 1 does not mean to be exhaustive: as a matter of fact, each layer depicts in a symbolic manner a set of contents, methodologies and technologies, each strongly dependent on the kind of application. For instance, in advanced services for the Cultural Heritage, the layer between the object and the smart application architecture comprehends (at least) advanced digital video instrumentation and exposure techniques, data compression algorithms, data storing methods, etc.

In this simplified and general representation, an object (meant as a content of any kind and complexity), is acquired through specialized media.

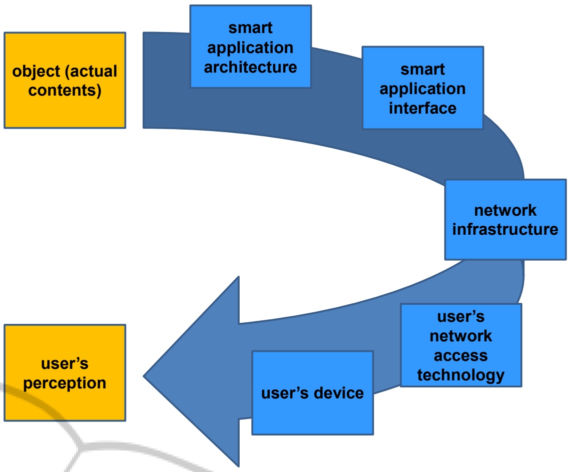

Figure 1: Main layers between contents and the user's perception.

Data are transmitted through a network infrastructure (e.g. a 100 Mbps fixed network), accessed by the user on the basis of his or her access technology (e.g. a WiFi on a 20 Mbps DSL) and through his or her device (e.g. a notebook or a tablet).

All the above factors contribute to the final perception. In particular, an appropriate transmission and reception of images and videos (such as HD streaming) strongly contribute to the user's overall perception. QoS management, thus, here meant as an appropriate bandwidth distribution, becomes a focal issue in PQoS and must be properly handled with. This is particularly important when groupwork activities are scheduled, such as lessons involving the simultaneous vision of high bandwidth-demanding contents. As a matter of fact, the lesson is address to a group, but, since each student is free to access information using his or her device and network access technology, supervision concerns individuals.

The paper is organized as follows: Section 2 extends the representation in Fig. 1 and proposes a simple definition of the factors of PQoS. Section 3 discusses an early architecture for enhancing dynamic QoS management in case of high bandwidth-demanding visual contents. In particular, the dynamic service allocation policies in (Toppan, A., 2012, Won-Kyu Hong, D., 2003) are revised and adapted to e/m-Learning requirements. Section 4 is devoted to concluding remarks, open issues and future work.

2 FROM REALITY TO VISUAL PERCEPTION

Before detailing the layers between an image or video and its perception, let us consider a simple example, referred to the steps in Fig. 1; the example considers a virtual visit to a museum and makes a distinction between tourists and students. While the former can be generally considered experienced and properly equipped, the latter cannot always be provided with either fast network technologies or devices and have little experience in the field of fine arts.

Consider a museum (object); roughly speaking, the smart application represents and manages access to the masterpieces, so as to allow the user to visit them virtually. A visit can be enjoyed through the application interface, generally interactive. The perceived quality of service depends on several technical factors, such as how the museum was filmed, represented and stored, how fast information is transmitted and received, how fast interactions take place, etc. The application can include streaming videos, transmitted through a network infrastructure (for instance, a 100Mbps wired dorsal) and reaching the user through his or her network access technology (for instance, a WiFi on a 20Mbps DSL from home) on his or her mobile device. The device is defined by several properties, such as screen dimension and resolution.

In summary, the issues that must be taken into account are of two kinds: (i) **personal factors:** taste, age, previous knowledge, culture or experience about some masterpieces, expectations, attitude towards the fine arts or specific art movements or artists; (ii) **equipment:** network connection, devices. All such factors are also time-variant. As for personal factors, in fact, consider a masterpiece that hit you very deeply in the past, particularly well exposed. Suppose to see it again after many years in a poor context or showed through low-quality media: the effect is almost bound to be disappointing. On the contrary, in case you couldn't appreciate a seriously damaged painting, you will probably enjoy a digital restoration. In this case, the young are less probably experienced and influenced by memories than adults are.

As for equipment, the enjoyable and profitable fruition of high bandwidth-demanding contents, especially involving HD images or videos (such as HD 3D), makes the difference between properly equipped amateurs and most schools realities. On the one hand, in fact, both network technologies, such as Gigabit Ethernet (GbE) for wired connections and Long Term Evolution (LTE) for mobile communications, as well as powerful tablets are already on trade. On the other hand, such facilities are neither available worldwide nor at all the students' disposal.

Accompanied by an appropriate network load management and dynamic bandwidth distribution through QoS techniques, these fast connections and high-quality screens would surely allow a good enjoyment contents.

Also on the basis of the above considerations, Fig. 2 extends the representation in Fig. 1 to the case of visual perception. This depiction underlines once more that PQoS depends on both technical and personal factors and tries to detail some aspects of the process that leads from a real object to a user's visual perception. Fig. 2 can be ideally divided in three vertical areas. The arrows on the left represent the main phases of the whole process, classified in "acquisition", "transmission/delivery" and "personal elaboration". In the mid of Fig. 2, each phase is divided into its main components. On the right of Fig. 2, the ovals indicate whether the phase is lossy or enhancing, both from the technical and personal viewpoint. In more detail (Fig. 2, upper part from left to right), the acquisition process involves digital acquisition and storage of the represented object.

In such phases, the real object is filmed or photographed through videocameras or other devices, on the basis of the application needs and the photographer's personal interpretation. Such data are then stored, according to the application architecture. In particular, techniques such as photo restoration and digital compression are applied. In this sense, thus, the acquisition process can be lossy or enhancing from the technical viewpoint and is also personal, due to the photographer's or environmental mediation. As far as the transmission/delivery process is concerned (mid portion from left to right in Fig. 2), it involves the wired network infrastructure and the user's network access and device. Since every telecommunication system aims at the most complete transmission of the information received, data are transmitted in such a way to preserve quality. In consequence, the user will receive information in a period of time which depends on actual network speed and bandwidth at disposal. This can mean that, in case of slow connections or very rich contents, a HD video can reach the user with several interruptions, so as to make it not properly enjoyable or useless for a lesson. Further factors depend on the user's device, such as screen size and screen resolution. In this sense, the transmission/delivery phase can be technically lossy, even though it does not imply personal judgement. Such judgement will begin during the personal elaboration phase.

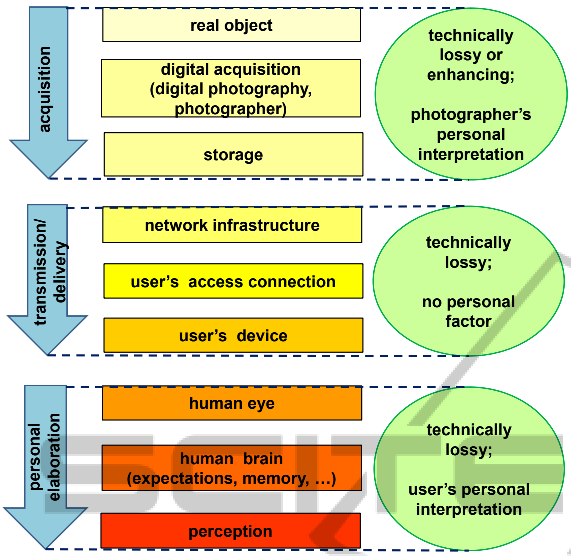

Figure 2: From the real object to perception.

As for the personal elaboration phase (bottom part of Fig. 2), the image or video reaches the human brain through the eyes and the complex process of perception takes place. This process is almost entirely personal, and can be considered a reconstruction based on genetic factors, environmental interactions and previous experiences (Arnheim, R., 1954, Ryan, 2005). This viewpoint is intentionally simplifying, but it can be useful when Smart Applications for the Cultural Heritage are considered. In this context, in fact, layers between real objects and human perception are particularly numerous and complicated.

As for PQoS, the whole system refers to the use of images and video streaming. The problem is particularly important when contents from the Cultural Heritage are involved.

PQoS is quite difficult to define and measure analytically. Still, some components can be identified. The following definitions try to give a contribute and simply intend to better characterize the problem.

PQoS is time-variant (PQoS = PQoS(t)) and, in the proposed approach, is a function of two components. The first is a technical component, here addressed to as TQoS = TQoS(t), which represents a time-dependent "Technical Quality of Service". TQoS varies over time for several reasons: think, for instance, that the quality of transmission depends on the bandwidth available, which is time-variant.

The second component is PQoS itself, a sort of personal factor, user's dependent and time-dependent, referred to the past, memorized in the brain, based on previous experiences, taste, expectations, etc. This component is here denoted by PQoS(t_{mem}), where t_{mem} roughly indicates a single instant, but comprehends all the times of memories, experiences, etc.

Let t_{now} be the current instant, when the image or video is being looked at. PQoS(t_{now}) can thus be represented as a recursive function f of TQoS(t_{now}) and PQoS(t_{mem}).

***Expression** E_1:* PQoS(t_{now}) = f(TQoS(t_{now}), PQoS(t_{mem}))

According to the representation in Fig. 2, TQoS(t_{now}) can be better detailed.

Let [$t_{start\text{-}acq}$, $t_{end\text{-}acq}$] be the time interval during which the image was acquired and stored; [$t_{start\text{-}tra}$ - t_{now}] denotes the interval during which the image or video was transmitted to the user's device.

"Quality of Acquisition" can be denoted by QoA([$t_{start\text{-}acq}$, $t_{end\text{-}acq}$]); in the same way, the overall "Quality of Transmission" can be indicated as QoT([$t_{start\text{-}tra}$ - t_{now}]); The "Quality of the Device" used to look at the object is QoD(t_{now}).

In summary, TQoS(t_{now}), quality of service perceived at time t_{now}, can be denoted as a function g of its technical components:

***Expression** E_2:* TQoS(t_{now}) = g(QoA([$t_{start\text{-}acq}$, $t_{end\text{-}acq}$]), QoT([$t_{start\text{-}tra}$ - t_{now}]), QoD(t_{now}))

The above expressions lead to:

***Expression** E_3:* PQoS(t_{now}) = f(g(QoA([$t_{start\text{-}acq}$, $t_{end\text{-}acq}$]), QoT([$t_{start\text{-}tra}$ - t_{now}]), QoD(t_{now})), PQoS(t_{mem}))

Whereas PQoS(t_{mem}) is strictly personal, the technical quality of service can be handled with more precisely. In visual mobile applications, for instance, one of the most important quality factors to be guaranteed is the sense of continuity of a video. While very fast technologies, such as Gbps transmissions, provide users with this feature, the problem must be handled with in slower ones.

In the considered case, most school environments have or will have to cope with this problem for a long time.

The following Section takes two types of data (HD videos and non HD) into account, discusses the feasibility of an appropriate video enjoyment through different network access technologies and proposes a method for the dynamic management of bandwidth release on the basis of content size and duration.

3 PROPOSED ARCHITECTURE

The increasing availability of rich contents from the Internet will force to consider technical network aspects in e/m-Learning applications. Such activities, in fact, can involve high bandwidth demanding contents, such as HQ images or streaming videos from the Cultural Heritage and used in History of Art lessons.

The paper refers to different visual contents. In the observations, visual quality, such as number of interruptions, is considered. To this purpose, a long video was needed, in order to make more observations.

When a teacher prepares a lesson, he or she must be aware of possible problems in some students' connections and devices. For instance, the teacher can use a fast Internet connection, find a beautiful HD image or HD streaming video and decide to ask the pupils to see it. Some students, on their hand, can use slower connections when they follow the lesson from home, access the image or video and see them badly or with several interruptions. The risk, especially where visual quality is fundamental, is that such pupils are not able to follow the lesson properly.

In order to handle with this situation, a possible approach can be the following. On the one hand, the teacher must be prepared (and indicated) which contents he or she can use and which cannot, also on the basis of the students' technologies. On the other hand, an appropriate schedule of activities, made also on the basis of resources, can prevent the inappropriate fruition of lessons.

In Section 2, a distinction was made between TQoS and PQoS. The term TQoS includes several technical factors, among which the so called Quality of Service (QoS), as meant in Telecommunications. QoS refers to techniques and protocols for assigning bandwidth properly to single users or groups and guarantee the desired performance to data flows and services. In context of schooling applications, data flows must be handled with on the basis of the different activities scheduled over time. In particular, quality levels must meet the needs of teachers and allow all the students to enjoy profitable lessons from distinct locations and using heterogeneous access technologies.

Also due to the very severe lack of funding in several countries, advanced contents are not at everyone's disposal, so that ad hoc QoS techniques and scheduling methodologies must be adopted.

In the following, some QoS methodologies are briefly recalled. Then, some considerations are made about streaming videos. In particular, the feasibility of their use in History of Art lessons in e/m-Learning environments is addressed. An architecture is then proposed for dynamic and profile-based QoS management, based on duration and data rate predicted for a lesson.

In the following, the concept of QoS management is briefly summarized, in order to better explain the proposed variant.

The ever-growing request of bandwidth in mobile advanced applications, as well as the Digital Divide discrimination, are leading to the development of more and more efficient methodologies for bandwidth optimization. Several techniques have been developed, such as Traffic Shaping (Gringeri, S., 1998), Policy-Based Traffic Management (Conchon, E., 2010, Fangming Z., 2008, Heithecker, S., 2007) and Quality of Service (QoS) (Chang Wook, A., 2004, Huang, J.H., 2006).

In the considered e/m-Learning scenario, QoS priority-based dynamic profiles in wireless multimedia networks are considered. These techniques (Naser, H., 2005, Song, S., 2006) allow to assign different priorities to distinct applications, so as to rearrange service quality in a dynamic way (Kamosny, D., 2006) and guarantee the desired performance to data flows. Among such methods, the platform proposed and tested in (De Castro, C., 2011, Toppan, A., 2012) can manage simultaneously two levels of priority: (i) among different users and (ii) within a single user's connection. In (i), those users whose profiles guarantee higher bandwidth, are proportionally assigned a greater part of the shared bandwidth. Case (ii) refers to each user, whose distinct services are assigned distinct priorities on the basis of necessity. Each profile, in fact, allows the real-time management of services, and a sort of priority parameter is used to queue the desired applications properly. The testbed involved 80 users approximately. This method is at the basis of the proposed variant, designed to meet the needs of e/m-Learning environments. The idea is the following: students and the teacher, as a group, have specific users' profiles. In case a scheduled lesson requires peak bandwidth for a HD streaming video enjoyment in a given time interval, the system analyzes the students' network access technologies and decides whether the schedule can be accomplished or must be modified.

In the proposed approach, in particular, an **e/m-Learning System** and a **Traffic Control Center** interact. A first feasibility evaluation is made by the e/m-Learning System; a second phase is accomplished by the Traffic Control Center on the basis of information received from the e/m-Learning System.

Some preliminary measurements about video streaming quality in case of heterogeneous access technologies are here reported. When a teacher schedules a high bandwidth-demanding task, he or she can tell the system in advance the desired period of time during which a peak bandwidth requirement will take place and to whom the necessary bandwidth must be assigned.

In this way, the minimal bandwidth needed to accomplish the task can be evaluated and compared to the students' access technologies. Such evaluations can, for instance, rely on the simple numerical observations in Tab. 1.

Before describing these measurements, it must be observed that several and often unpredictable factors contribute to a mobile network connection speed, such as time, number of users connected, position, data rate, etc.

The apparently straightforward time access formula $t_{access} = D_{dim}/Net_{speed}$, where t_{access} represent the total access time, D_{dim} the data to be processed and Net_{speed} the network performance, is in fact only indicative. Each of its components depends on several, often time-variant factors. In particular, Net_{speed} varies over time and instantaneously.

Tab. 1 refers to a HD streaming motion picture and its non HD version. The film lasts about 105 minutes and is about 3GB in the HD version and 2GB in the non HD version. A long motion picture and no (generally shorter) specific content from the Cultural Heritage was used in order to make several observations during a long period. Some examples from the Cultural Heritage are cited and observed afterwards.

The effective measurements refer respectively to the HD and non HD versions accessed through: (i) a WiFi based on a wired 100Mbps (ii) a WiFi based on a 20 Mbps DSL and (iii) a 2Mbps GPRS.

Tab. 1 reports the total number of interruptions observed, but the discussion refers to the average. In case of 100 Mbps transmission, the data to be processed fits the network capability (0.9 interruptions per minute in the HD version and 0.6 in the non HD one). The streaming quality declines with 20 Mbps access technology (2 and 1.5 interruptions per minute respectively). In case of GPRS access, neither the HD nor the non HD videos are not even accessible.

A Gbps connection would allow an excellent streaming quality, as it already happens in North America with streaming TV, but it is quite rarely the case of schooling institutions and students all over the world.

Table 1: Network technology and streaming quality.

Data	Access	Quality
3GB	WiFi on 100Mbps	97 int./ 105 min.
2GB	WiFi on 100Mbps	60 int./ 105 min.
3GB	WiFi on 20Mbps	210 int./ 105 min.
2GB	WiFi on 20Mbps	160 int./ 105 min.
3GB	2Mbps	Not accessible
2GB	2Mbps	Not accessible

As anticipated, the above examples do not refer to contents from the Cultural Heritage, due to measurements needs but also to the risk of violating copyright. Some examples from the Cultural Heritage are reported in the following, with no image, and so are related observations . In particular, a self-portrait by Van Gogh (www. vangoghmuseum.nl/vgm/index.jsp?page=1728&collection=1285&lang=en, as of December 26th 2013) was first accessed through a low resolution screen and then through a good resolution smartphone. Despite the screen dimension, the effect was much better on the smartphone. Several interesting video contents from the Cultural Heritage are available at www.vimeo.com. In particular, the HD video at http://vimeo.com/47694417 (as of December 26th 2013) about a Silver Athenian Tetradrachma, lasted 1,32' and was accessed with no interruptions using a 100 Mbps, 1 interruption with a 20 Mbps DSL and 3 stops with a GPRS connection.

Talking about the architecture, dynamic bandwidth management methods aim at assigning bandwidth on the basis of different profiles, rights and actual needs. The proposed method simply tries to optimize bandwidth assignment on the basis of the activities planned during a lesson: when a teacher decides he or she wants to show his or her students some highly bandwidth-demanding contents, the early architecture proposed takes into account all the people involved and tries to manage the teacher's request.

A simple example can be the following: a lesson can involve an initial, introductory 15 minutes talk of the teacher to the students and, successively, a HD streaming video about 20 minutes long that the teacher has decided to show to his or her students.

During the first 15 minutes, no high bandwidth-demanding activity is involved (voice only), so bandwidth assignment profiles can be kept low. In the following 20 minutes, students need much more bandwidth; in order not to be displayed videos with several interruptions, their connections must be appropriate and their bandwidth profiles kept high.

In the proposed approach two kinds of feasibility controls are made, using information about the students' access technologies and network traffic predictions.

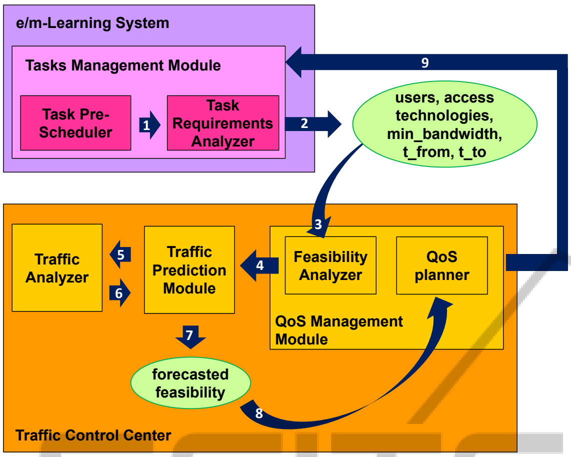

Figure 3: Proposed Architecture.

Fig. 3 illustrates the proposed architecture, in which the **e/m-Learning System** and the **Traffic Control Center** interact.

The e/m-Learning System contains several components, among which the **Task Management Module**, whose main sub-modules are the **Task Pre-Scheduler** and the **Task Requirements Analyzer**. The former collects the teachers' proposed schedules (step 1 in Fig. 3), the latter analyzes each task involved and, on the basis of the users' access technologies, makes a first feasibility evaluation, on the basis of the measurements reported above. In consequence, some students can simply be suggested to use their home DSL rather than GPRS from outside. This can be the case of a tablet which uses both technologies: WiFi from home DSL or the GPRS USIM. In the same way, if several students are bound to come across connection problems, the teacher can be asked whether a non HD version can meet his or her teaching needs.

This first phase accomplished, the Task Requirements Analyzer (step 2) returns the following data: users, their network access technologies, the minimal bandwidth to be guaranteed to everyone and the time interval [$t_{\_from}$, $t_{\_to}$] of the task.

This information (step 3) is forwarded to the **Traffic Control Center**, in particular to the **Feasibility Analyzer** of the **QoS Management Module**.

The Feasibility Analyzer forwards the information to the **Traffic Prediction Module** (step 4). This module interacts with the **Traffic Analyzer** (steps 5, 6) and the final decision ("forecasted feasibility" in step 7) is forwarded to the **QoS Planner** (step 8) and, finally, to the Task Management Module (step 9).

In particular, step 9 can be detailed as follows: in case the task is not forecasted as feasible, the e/m-Learning System is informed and the teacher can decide to decide a new schedule or accept lower-quality videos. In case the task is feasible, the QoS planner produces a QoS schedule and the e/m - Learning System is acknowledged.

4 CONCLUSIONS

In this paper, the use of advanced, visual contents in History of Art lessons was discussed from the viewpoint of visual quality. In particular, the concept was faced of visual perception of goods put at disposal by smart e/m-Learning applications using the Cultural Heritage, and so were the technical factors that contribute to the final perception were investigated. In this context, the problem becomes particularly relevant of image or video quality, especially if high-bandwidth demanding contents accessed in real-time are involved.

Two distinct but related aspects were discussed, concerning advanced visual contents from the Cultural Heritage and their use in smart education environments, referred to images and videos. The first was "Perceived Quality of Service" (PQoS) in visual environments. Second, the following problem was discussed: since learning contents can be accessed from home or outside using heterogeneous network access technologies (and, in consequence, different speeds), in a lesson involving high bandwidth-demanding contents, such as HD streaming virtual visits to museums, the bottleneck is data dimension. A possible solution to prevent teachers from selecting visual contents that run the risk of being inappropriately displayed by some pupils was proposed. The proposal, currently being under development phase, was an early architecture for the dynamic management of bandwidth release on the basis of content size and duration.

Further work will be devoted to a better definition of Perceived Quality of Service and its components, the role of memory and expectations and to a refinement of the proposed architecture.

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