Analysis of End-to-End QoS for Networked Virtual Reality Services in UMTS

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ABSTRACT

Virtual reality services may be considered a good representative of advanced services in the new-generation network. The focus of this article is to address quality of service support for VR services in the context of the UMTS QoS framework specified by the 3G standardization forum, the Third Generation Partnership Project. We propose a classification of VR services based on delivery requirements (real-time or non-real-time) and degree of interactivity that maps to existing UMTS QoS classes and service attributes. The mapping is based on matching VR service requirements to performance parameters and target values defined for UMTS applications. Test cases involving heterogeneous VR applications are defined, using as a reference a general model for VR service design and delivery. Measurements of network parameters serve to determine the end-to-end QoS requirements of the considered applications, which are in turn mapped to proposed VR service classes.

INTRODUCTION

The next-generation network is expected to support a great variety of applications with different quality of service (QoS) requirements. Virtual reality (VR) services, representing a step beyond "traditional" multimedia, aim to provide an advanced human-computer interface, allowing a user to interact with other users in a simulated 3D environment. Such services are characterized by high-quality 3D graphics, integrated multimedia components, support for multiple users, and unpredictable traffic flows due to dynamic user interactions. Great market potential for VR may be foreseen in areas such as entertainment, e-commerce, education/training, various simulations, and data visualizations. Bringing this potential to realization depends on meeting the QoS requirements for such applications.

Standards proposed by the Third Generation Partnership Project (3GPP) define a layered QoS architecture to be used in the Universal Mobile Telecommunications System (UMTS) [1]. Specifications define four UMTS QoS classes intended to cover a broad range of applications, primarily distinguished based on sensitivity to delay [2]. The UMTS QoS classes are defined at the application layer in terms of end-to-end performance expectations, and are supported through interaction of underlying bearer services. Within existing specifications, there is no clear description provided of the requirements for VR services. Our purpose in this article has been to propose a classification of VR services based on delivery requirements (real-time or non-real-time) and degree of interactivity that maps to existing UMTS QoS classes. The mapping is based on matching VR service requirements to performance parameters and target values defined for UMTS applications.

Case studies have been conducted in an emulated network environment to determine the end-to-end requirements of a number of heterogeneous VR applications, thus providing experimental verification of the proposed service classification and mapping. The applications used as case studies are considered in the context of a general reference model proposed for VR service design and delivery. The model is proposed in [3] and defines key service parameters in the form of *service profiles* needed for VR service adaptation in response to end-user capabilities/preferences. Case study applications considered in this work are classified as belonging to VR service classes based on measurements of network parameters defined in the service profile. We provide a discussion of achieved results and give concluding remarks.

GENERAL REQUIREMENTS

VR SERVICE REQUIREMENTS

VR applications present a challenge in networking for a number of reasons. These include providing support for multiple distributed users (sometimes up to tens, hundreds, or possibly thousands) taking part in a shared virtual environment (VE) using dynamic forms of communication, and the

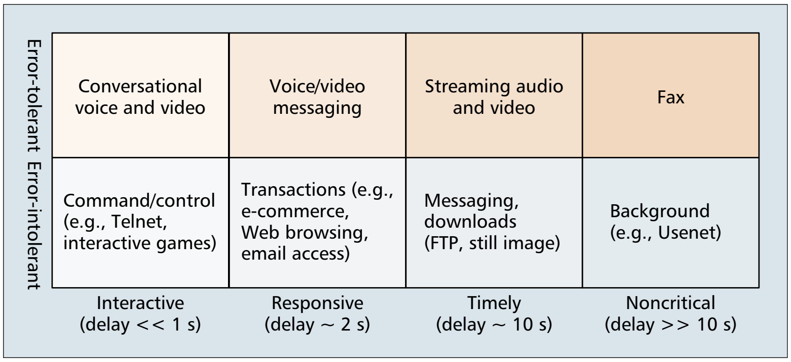


Figure 1. *A Model for user-centric QoS categories.*

integration of media components such as 3D graphics, text, streaming audio, and video. Key network issues relating to networked VR applications have been identified as bandwidth, network distribution, latency, and reliability [4].

Available bandwidth is one of the fundamental issues dictating the possible size and content of a VE. The required bandwidth corresponding to a VR service depends on the number of users, distribution architecture (unicast, multicast, broadcast), and VR/multimedia content. The network distribution scheme used affects the scalability of a VE, with multicast distribution providing a scalable solution. Another important issue is latency, expressed in terms of delay and delay variance (jitter). Latency requirements stem from user perception of real-time interactivity with a VE and other users or autonomous processes in the environment. Reliability is an issue that often forces a compromise between bandwidth and latency, with real-time applications often tolerating loss better than delay.

As an important subset of VR applications, collaborative VEs (CVEs) impose certain requirements due to the fact that collaboration between multiple users is often a real-time and highly interactive process. In related work [5], an extensive review is conducted of various distributed systems. To summarize results from the review, we quote some of the findings. In a collaborative engineering VR system, an estimated maximum delay requirement of 100 ms is suggested. A different study suggested that 200 ms delay might be considered acceptable in a CVE, as long as there is practically no jitter. The authors showed that in a session involving object manipulation tasks, performance in a network with 10 ms delay and considerable jitter was nearly the same as in a network with 200 ms delay and no jitter. Generally quoted requirements for distributed simulations with tightly coupled interactions are 100 ms delay for update messages and 50 ms jitter.

Requirements depend on the type and purpose of the application. CVEs designed for purposes such as performing complex manipulative tasks require minimal latency and high bandwidth, while many CVE applications are designed so that users spend most of the time navigating in 3D space, and less time manipulating objects and interacting with others. Such CVEs may be considered more tolerant in terms of network latency.

Numerous multiplayer computer games (e.g., Unreal, Quake) may also provide an interesting application area for VR services. Examples include first person shooter (FPS) games and real-time strategy (RTS) games. Bandwidth requirements depend on the number and distribution of users, along with the applied distribution scheme. In an RTS game, latency up to 500 ms may be considered acceptable (as long as jitter is low), while games requiring tight hand-eye coordination such as FPS demand that latency remain less than 100 ms. It has been argued that a player's success in an FPS game can be critically affected with ping times (round-trip times between client and server) measuring over 150 ms [6].

The integration of streaming audio/voice or video into a VE may enhance the sense of immersion perceived by users in applications such as virtual conferencing, CVEs, or multiplayer games. Overall quality is dependent on both quality of auditory and visual information, as well as synchronization quality. Important for VEs is the notion of animation streaming, in which case information regarding facial or body positions of avatars is streamed over the network. Delay, jitter, and synchronization with other media components are factors influencing overall quality.

Existing QoS Standards: UMTS QoS Classes

International Telecommunication Union — Telecommunication Standardization Sector (ITU-T) Recommendation F.700 [7] provides a general methodology for constructing multimedia services where a service is decomposed into a set of communication tasks, each of which handles a set of media components. In ITU-T Recommendation G.1010 [8] a model for multimedia QoS categories is defined, taking into account user expectations for a wide range of multimedia applications (Fig. 1).

ITU-T Recommendation Y.1541 [9] groups end-to-end performance parameter values for packet transfer in IP-based networks into six distinct QoS classes. In accordance with these Recommendations, currently available 3GPP specifications [1] provide a classification of UMTS services into four QoS classes depending on sensitivity to delay of application traffic. A brief description of each class is given.

Conversational class: represents highly delay-sensitive conversational streaming applications. Examples include telephony speech, voice over IP, and videoconferencing. Limits for acceptable transfer delay are very strict, along with requirements on preserving the time relation between different stream entities.

Streaming class: represents real-time streaming applications that are primarily unidirectional. This scheme applies when the user is looking at (listening to) real-time video (audio). The class is characterized by limited delay variations, with no requirements on low transfer delay.

Interactive class: represents the classical data communication scheme characterized by the request-response pattern of the end user. Example applications include Web browsing and database retrieval. A key characteristic for QoS is low bit error rate for transferred packets.

Background class: The fundamental characteristic of this class is that the destination is not expecting the data within a certain time. Data can be sent and received in the background, with low bit error rate and no specific requirements on delay.

The defined classes are specified at the application level with an outline given of end-user/application QoS requirements for example applications in terms of key performance parameters and target values. Indicated are the upper and lower boundaries for applications to be perceived as acceptable by the user. Our focus in this article is on UMTS standards, and attempting to classify and map VR services to specified UMTS QoS classes.

Proposed Mapping of VR Services to UMTS QoS Classes

Based on referenced work and existing standards, we propose a classification of VR services defining five distinct service classes. The main distinguishing factors used to classify the services are sensitivity to delay and degree of interactivity. Shown in Table 1 is a mapping of the proposed classes to UMTS QoS classes with a mapping of VR service requirements to performance parameters and target values given for UMTS classes.

Highly interactive VR applications (e.g., CVEs, simulations, network games) are comparable to UMTS conversational class services in terms of strict delay requirements. While the term *conversational* is used in the UMTS service classification (as telephony speech, VoIP, and videoconferencing are the most well-known uses of this scheme), we prefer the terminology *real-time interactive* when classifying VR services with comparable network requirements. The term *interactivity* is commonly used when discussing the QoS of VR services and has been defined as a user's perception of the ability to interact with objects and other users in a multi-user VE, including user

UMTS QoS classes	VR service classes	Media types	Example VR services	Example VR applications	Classification parameters			
					Degree of sym.	Delay	Delay variation	Information loss
Conversational class	Hard real-time interactive VR	Data, graphics, audio, video, text	Distributed simulations	Tightly coupled flight simulation	Two-way	End-to-end one-way delay < 100 ms	50 ms	< 3% packet loss ratio (PLR)
			Tightly coupled CVE	Collaborative engineering and design; telesurgery	Two-way	End-to-end one-way delay < 100 ms	N/A	Zero
			Virtual conferencing	Virtual chat space: 3D graphics, audio communication	Two way	End-to-end one-way delay < 150 ms	< 1 ms (for conversational voice)	< 3% PLR
			Multi-user interactive games	First person shooter game	Two-way	End-to-end one-way delay < 100 ms	N/A	Zero
	Soft real-time interactive VR	Data, graphics, text	Loosely coupled CVE	Virtual multi-user shopping center	Two-way	End-to-end one-way delay < 400 ms	N/A	Zero
			Multi-user interactive games	Real-time strategy game	Two-way	End-to-end one-way delay < 500 ms	N/A	Zero
Streaming class	VR with integrated real-time streaming media (one-way)	Data, graphics, audio, video, text	VE with integrated video/audio	Virtual movie theater	Primarily one-way	Startup delay < 10 s Lip-synch. ±80 ms	< 2 s	< 2% PLR (video) < 1% PLR (audio)
			Virtual humans on the Internet	Virtual newscaster: streaming audio, video, and animation	Primarily one-way	Start p delay < 10 s Lip-synch. (animation and audio) ±80 ms	< 2 s	< 2% PLR (video) < 1% PLR (audio) < 0% PLR (animation)
			VE with integrated audio	VE with background music	Primarily one-way	Start p delay < 10 s	< 2 s	< 1% PLR
Interactive class	Non-real-time interactive VR	Data, graphics, text	Virtual place simulation on the Internet	Virtual city tour; user navigates through multiple virtual spaces	Primarily one-way	One-way delay < 4 s/new space	N/A	Zero
			Database retrieval	3D dynamic data visualization; user interacts with data	Primarily one-way	One-way delay < 4 s/view	N/A	Zero
Background class	Non-real-time best effort VR	Data, graphics, text	Background download of VE	VE requiring only initial download; all subsequent interactions/object manipulations occur locally	Primarily one-way	No special requirements; download time depends on size of VE components	N/A	Zero

Table 1. *The proposed mapping of VR service classes to UMTS QoS classes.*

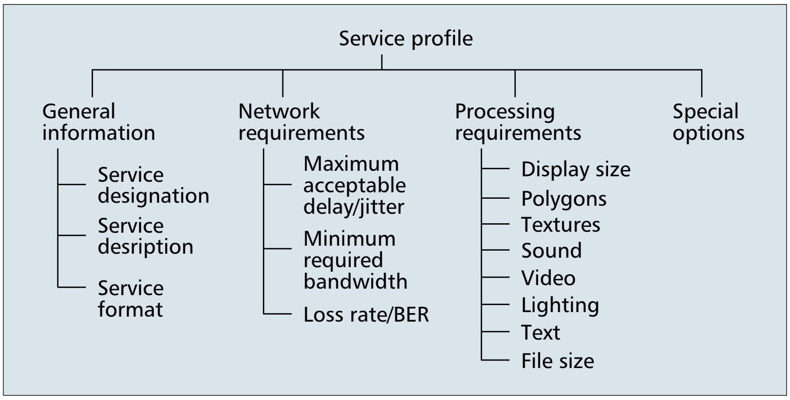


Figure 2. *The generic VR service profile.*

evaluation of choices and extent of interaction [5]. Due to the fact that network requirements depend on the nature of the application, we find it important to distinguish between *hard real-time* and *soft real-time interactive VR* services.

The given network requirements for streaming media components in VEs correspond to standard requirements for audio and video, with exact values for network parameters depending on the specific type of codec. Delay variation values correspond to values given in 3GPP specifications. Due to the fact that the stream is aligned at the receiving end, the highest acceptable delay variation is given by the capability of the time alignment function of the application. In VEs where spatial audio/video is involved, requirements also depend on the relative position of the media in the virtual world.

We map VR services characterized by an end user interacting with remote equipment to the UMTS interactive QoS class. Often we are looking at services with requirements comparable to classical Web browsing, including VEs where the user navigates from one virtual space to another, or requests downloads of additional VE objects. The *non-real-time best effort VR* class includes applications that are not time-dependent. This refers to single-user cases when the user simply downloads a VE and performs all other interactions with the environment locally.

Table 1 outlines the proposed target QoS values representing end-to-end performance between communicating entities. In order to realize a certain network QoS, a bearer service needs to be defined with characteristics and functionality from the source to the destination of a service. Due to the fact that a specific VR application may consist of a collection of VE objects containing various media types, a mapping of application requirements to network parameters requires specifying the requirements of each media type, along with any necessary synchronization.

VR Service Profile

We consider VR services in the context of a general model proposed for VR service design and delivery that enables transparent user access [3]. The functionality of the model is based on matching the parameters of a VR service profile with restrictive parameters of a client profile to achieve service adaptation resulting in the highest achievable quality, from the point of view of the user and the VR service provider. Applications we consider as case studies are classified as belonging to proposed VR service classes based on measurements of network parameters identified in the VR service profile.

The generic VR service profile (Fig. 2) contains four sets of parameters: general service information, processing requirements, network requirements, and special options (parameter set introduced to allow upgrade of existing parameters or to enable new parameter definitions, e.g., new types of audio/video codecs, text specification in terms of font, style, and size).

The indicated service parameters address QoS at the application and network levels, and can be related to parameters characterizing a bearer service as defined by 3GPP. According to specifications [2], an application will specify its network QoS by negotiating a bearer service with:

- A specific traffic type: guaranteed/constant bit rate, non-guaranteed/dynamically variable bit rate, real-time dynamically variable bit rate with minimum guaranteed bit rate
- Traffic characteristics: point-to-point, point-to-multipoint
- Maximum transfer delay
- Delay variation
- Bit error rate
- Data rate

Exact bearer service attributes and their relevancy for each UMTS QoS class can be found in [1]. Case studies have been conducted to determine the end-to-end requirements of a number of heterogeneous VR applications, which serve to verify the proposed service classification and mapping.

Case Studies

Measurements were conducted in a laboratory LAN involving service parameters to determine end-to-end QoS requirements. Achieved results serve to classify test case applications as belonging to proposed VR service classes.

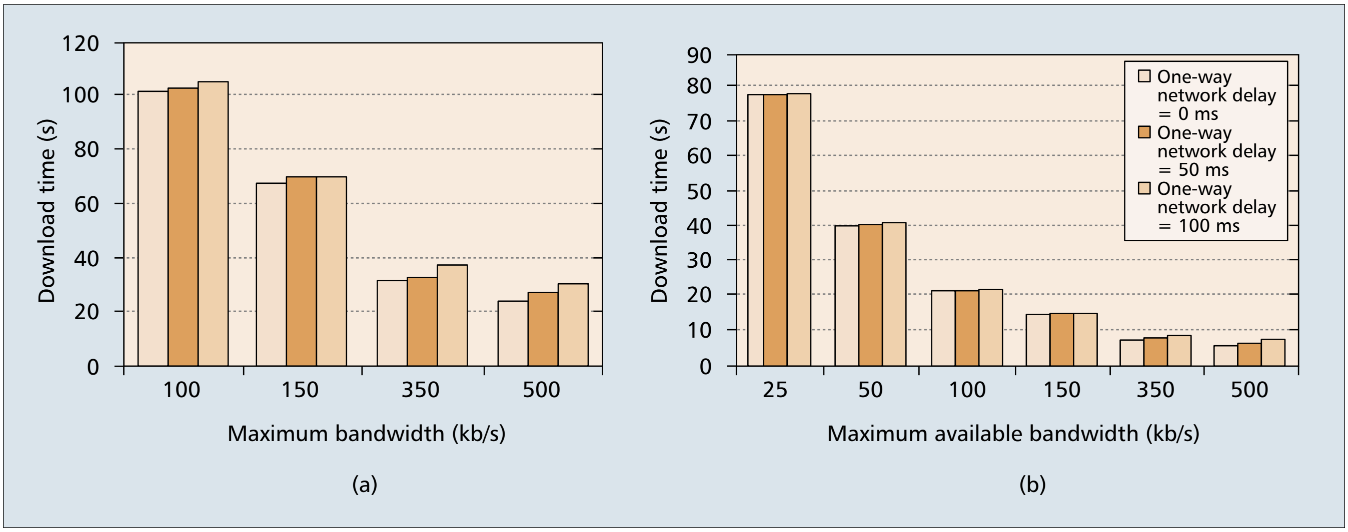
Requirements are determined by testing the effects of various network conditions on user-perceived quality. Under certain conditions (e.g., an end user with limited bandwidth due to access network capabilities), a service may not achieve its intended functionality and may therefore be considered unacceptable.

The testbed LAN consisted of four PCs and one workstation connected by a 10 Mb/s Ethernet LAN. Delay in the LAN was measured (using ping) to be less than 1 ms and packet loss 0 percent. For measurement purposes, traffic between endpoints was routed over a PC with the NIST Net software network emulater tool installed. NIST Net was used to set certain network conditions such as bandwidth limitations, delay, jitter, and loss

Case studies were organized into two sets of measurements:

- *Single-user VEs*: thematic virtual world, conversational virtual character
- *Multi-user VEs*: multiplayer game, virtual community

Single-User Virtual Environments — In the case of single-user VEs, only interactions between the user and the service were observed,



■ **Figure 3.** *Download times for gallery: a) HQ version; b) LQ version.*

rather than interactions between multiple users. Our research was oriented toward requirements for VEs on the Internet, where one of the key issues was time necessary for scene download. User interactions may trigger additional network traffic by requesting one-way audio/video streaming or additional file download. Two test cases were considered.

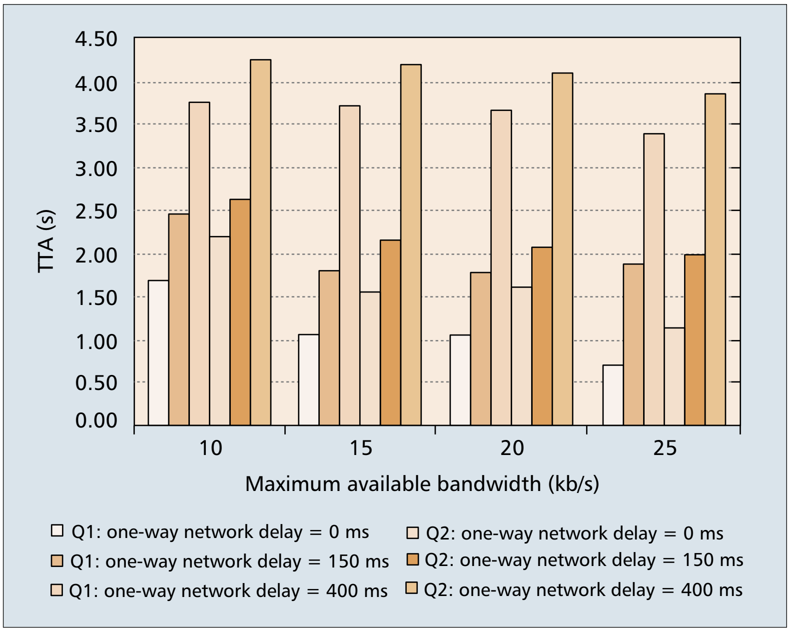
In the first case, a user accesses a thematic virtual world: a virtual phone gallery located on a Web server. The only generated network traffic is HTTP/TCP traffic during scene download. The VR service was implemented in two versions differing in complexity: *high quality* (HQ) and *low quality* (LQ). The two versions differ in terms of display size, number of polygons, lighting complexity, texture size(s), texture color depth, audio clip size, and file size. Measurements of download time (for the entire gallery) corresponding to different network conditions emulated using NIST Net are shown in Fig. 3. Loss probability was kept at 0 percent. Bandwidth limitations and delay correspond to one-way values, and were set in both the uplink and downlink.

The idea is to determine the network requirements of the service such that download time is considered acceptable by the end user. Depending on end-user network/terminal capabilities and the time considered acceptable for download, the appropriate service version is returned to the user.

In the second test case, we look at a conversational virtual character designed for the Web that is capable of having a meaningful conversation with a user who types in the input [9]. The animated virtual character (Java applet) can be controlled by JavaScript and instructed to talk. Speech is stored on a server in the form of audio (.au) files and MPEG-4 facial animation files (.fba). Measurements were performed to determine the time necessary for the virtual character to respond to a question typed by the user (time to answer, TTA). This involved the generation of an .au file and an .fba file on the server side that are streamed across the network to the end user. TTA was measured for responses generated based on two different length questions (Q1 and Q2), corresponding to different length responses. Figure 4 shows measured TTA values under different network conditions. Once again, values for bandwidth and delay correspond to one-way values, and were set in both uplink and downlink directions.

The user-perceived quality of virtual characters depends largely on the purpose of the application (e.g., entertainment, commerce, education). The issue is to determine the requirements of the application in order for it to be deemed functional and attractive. In our case, long response delays during the chat reduce the user feeling of real-time interactivity. For practical implementation, experience shows that TTA within the range of 1–2 s would be acceptable.

Multi-User Virtual Environments — In multi-user VEs, multiple users from distributed locations can communicate, collaborate, or interact with each other and the environment. Such services often require large bandwidth and low latency. In order to consider some of the require-



■ **Figure 4.** *Measurements of TTA for conversational virtual character.*

Example prototype applications	Corresponding VR service class	Data rate	Delay	Delay variation	Info. loss
Multiplayer shooting game	Hard real-time interactive VR	Min ≈ 24 kb/s required in the downlink and 31 kb/s in the uplink direction (four simultaneous users — requirements depend on the number of users)	One-way delay < 100 ms	< 30 ms	Zero
Multi-user virtual community (communication only using gestures and text box)	Soft real-time interactive VR	< 1 kb	One-way delay < 400 ms	N/A	Zero
Conversational virtual character on the Internet	Non-real-time interactive VR	Audio ≈ 10 kb/s Animation MPEG-4 FBA ≈ 2.4 kb/s	Response time < 2 s	N/A	Zero
Virtual mobile phone gallery (high-quality version)	Non-real-time interactive VR	380 kb/s	<30 s for complete download (< 4 s/ phone)	N/A	Zero
Virtual mobile phone gallery (low-quality version)	Non-real-time best effort VR	70 kb/s	<30 s for download	N/A	Zero

Table 2. *Mapping of test case applications to proposed VR service classes.*

ments of such services, measurements were performed using two applications.

In the first application, users took part in a multiplayer FPS computer game known as *Medal of Honor*, characterized by high-quality 3D worlds that utilize the powerful Quake III game engine. Measurements were performed to determine effects of bandwidth limitations, delay, and jitter on user-perceived quality. We tested the application using two different setups: one involving two simultaneous users, and the other involving four simultaneous users. In the case of two users, one user hosted the game (*host player*) while the other user joined in (*joinint player*)/ Gemerated traffoc was dynamic in nature due to dynamic user interactions. Measurements showed that a minimum of approximately 17 kb/s in the downlink direction (from the host to the joining player) and approximately 31 kb/x in the uplink direction (from the joining player to the host) is necessary in order to play the game. Delay effects were measured by setting various delays and asking players to comment on the quality of fair play. Delay remained unnoticed by the host player, while at a one-way delay of 100 ms (200 ms round-trip time) the joining player reported noticeable delay. Jitter effects were reported as only slightly noticeable at a set jitter of 40 ms in each direction.

When four users simultaneously took part in the game (one user hosted the game, and three additional users joined), it became apparent that increased bandwidth was necessary in the downlink direction. Measurements showed that a minimum of approximately 24 kb/s (downlink) is necessary in order to play the game. Delay and jitter requirements remained consistent with values determined for two simultaneous players. Although it is evident in this case that an increase in the number of simultaneous users increases bandwidth requirements, further measurements would be necessary to investigate the exact relationship between number of users and bandwidth for a particular application. In addition to the number of users, requirements are also affected by the distribution architecture, location of control (centralized or distributed), and the VR/multimedia content.

The second multi-user VE test case involved a shared VE built on Blaxxun's Virtual Worlds Platform that allows multiple users to interact. A client-server architecture is used to distribute updates among members in real time. Changes resulting from a user's actions need to be made visible to other users in a consistent manner to achieve real-time interactivity, making delay a key factor determining user-perceived quality. Users communicated using gestures, with measurements conducted to determine delay allowed in order to maintain acceptable user-perceived real-time interactivity. End-to-end delay was measured from the moment one user triggered a waving gesture until that gesture was made visible to the other user. Delay values up to 300 ms in each direction remained practically unnoticed by users. At 400 ms delay in each direction became noticeable. Specific values of acceptable delay depend on the nature of the interactive VR application. In this particular scenario, involving communication through gestures, delay is more tolerable than in multi-user interactive FPS games.

Discussion of Results

A mapping of applications addressed as case studies to proposed VR service classes is based on achieved test results. The mapping is given in Table 2. When using mobile devices or computers without VR-specific input and output devices, a user's sense of immersion is limited by device capabilities, affecting the mapping and user-perceived QoS. For example, when a user is served an adapted lower-quality service version as opposed to a higher-quality version, the QoS mapping could change from conversational to interactive class.

Due to strict delay requirements and high interactivity, we classify the multi-user shooting game as a hard real-time interactive VR application. Tests performed using the Blaxxun virtual community showed that delay became noticeable at approximately 400 ms (end to end). Stricter delay limitations were not necessary with participants interacting using only gestures. This application was therefore classified as belonging to the soft real-time interactive VR service class.

The conversational virtual character is classified within the non-real-time interactive VR service class due to the interactive nature of the chat. In addition, .fba and .au files are streamed from the server; however, the client player waits for complete file download prior to playing the response.

The virtual mobile phone gallery, implemented in the HQ version, may be considered as belonging to the non-real-time interactive VR service class due to the fact that each mobile phone model located in the gallery is downloaded only when the user falls within a certain range of that particular model. Thus, a change in the user's viewpoint may cause additional download. Requirements on delay are therefore necessary in order to prevent deterioration of navigational quality. The LQ gallery version downloads the entire gallery at once and is mapped to the non-real-time best effort VR service class, with no special requirements on delay. A data rate of approximately 70 kb/s is shown as needed in order for download time to be less than 30 s. However, this may be considered a soft requirement depending on particular user expectations regarding download time.

Summary and Conclusions

In this article we have addressed end-to-end QoS support for VR services in the context of the UMTS QoS framework specified by 3GPP. We have proposed a classification of VR services based on delivery requirements and degree of interactivity that maps to existing UMTS QoS classes. The mapping is based on matching VR service requirements to performance parameters and target values defined for UMTS applications. A number of case studies have been presented involving heterogeneous VR applications that serve to verify the proposed service classification and mapping. Key VR service parameters affecting requirements are identified using as a reference a general model for VR service design and delivery. Measurements of network parameters serve to determine the end-to-end QoS requirements of the considered applications, which are in turn mapped to proposed VR service classes.

We have demonstrated that the end-to-end QoS requirements specified for UMTS services have met the requirements of a proposed VR service model in an emulated network environment. Future steps will focus on determining support for VR services in an actual UMTS network.

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Biographies

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