Performance Evaluation of Networked Virtual Reality Services in a GPRS Network

Igor Perović
Core Network Department
VIPNet d.o.o.
Zagreb, Croatia
i.perovic@vipnet.hr

Lea Skorin-Kapov
Research and Development Center
Ericsson Nikola Tesla
Zagreb, Croatia
lea.skorin-kapov@etk.ericsson.se

Danko Vilendečić
Department of Telecommunications
FER, University of Zagreb
Zagreb, Croatia
danko@tel.fer.hr

Abstract—**The General Packet Radio Service (GPRS) network represents an intermediary step between GSM and 3G mobile systems, providing a solution for IP communication between mobile systems and Internet hosts. With packet switching capabilities and a significant increase in data rates comes the potential of accessing advanced Internet services using a mobile terminal. With integrated multimedia components, 3D graphics and real-time interactivity, networked virtual reality (NVR) services may be considered a good representative of these advanced services. This paper examines the capability of currently available GPRS network resources in supporting the Quality of Service (QoS) requirements of NVR services. Measurements of selected QoS parameters have been performed using three different NVR applications, while setting different QoS parameters defined in the Home Location Register (HLR). Results are analyzed to determine the feasibility of deploying NVR services over GPRS networks.**

Networked Virtual Reality; General Packet Radio Service; Quailty of Service

I. Introduction

The development of the new generation network (NGN), which is envisioned as the convergence of multiple independent networks into a single, unified, broadband network, is driven by the promise of new and advanced services and applications [1]. Networked Virtual Reality (NVR) may be considered a new service based on the merging of multimedia computing and telecommunication technologies. However, with integrated multimedia components and perceived "real-time" interactivity, NVR services impose certain Quality of Service (QoS) requirements at both the user/application level and the underlying network [2]. This implies that various access networks through which users access NVR services must provide sufficient bandwidth and satisfactory values for latency, jitter and reliability in order to support those services.

Several attempts have been made at identifying NVR communication requirements. For example, the effects of latency and jitter on human performance were measured in [3], with multiple users cooperating on a teleoperation task in a collaborative virtual environment. Similarly, [4] discusses the effects of latency and jitter on haptic force feedback display in the teleoperation of a distant microscope, while [5] describes measurements performed in an emulated network environment on four heterogeneous NVR applications. However, no attempt has yet been made at testing the performance of NVR applications when accessed through currently available wireless access networks. More specifically, the General Packet Radio Service (GPRS) network represents a possible choice for accessing NVR services in cases when standard wireline or 802.11 networks are not available, and/or the user needs to maintain constant mobility (e.g. travelers).

The General Packet Radio Service (GPRS) network represents an intermediary step between 2G and 3G mobile systems, providing a solution for IP communication between mobile systems and Internet hosts. With packet switching capabilities and a significant increase in data rates comes the potential of accessing advanced Internet services using a mobile terminal. Previous research on QoS in GPRS networks dealt with defining QoS management, providing an overview of QoS sensitive network elements [6] as well as measuring the effect that various parameters have on QoS. Influence of different radio resource allocation schemes on QoS were described in [7]. Dynamic radio resource allocation scheme showed better results than static radio resource allocation scheme, which is much easier to implement. In [8] analysis of Internet access over GPRS was done and shown inefficiency in the way the combination of transport control protocol (TCP) and GPRS utilizes increasing system capacity. Slow Start and Congestion Avoidance procedures are blamed for this inefficiency. Several papers are dealing with different types of traffic carried over GPRS: WWW [9], TCP [10], Voice over IP [11].

In this paper, we examine the capability of currently available GPRS network resources in supporting the Quality of Service (QoS) requirements of NVR services. Measurements of selected QoS parameters have been performed using three different NVR applications. Results are analyzed to determine the feasibility of deploying NVR services over GPRS networks.

The paper is organized as follows: section II describes the general GPRS architecture and QoS parameters in GPRS. Sections III and IV cover the applications and the environment that were used to carry out measurements. Results and analysis for measurements performed on three multi-user virtual reality applications are presented in section V, while section VI concludes the paper.

II. GPRS Architecture and QoS

The basic idea of the GPRS network is providing a packet switched connection with the possibility of allocating up to eight radio channels for one session. This enables data rates of up to 115 kbit/s, as compared to Global System for Mobile Communication (GSM) with the possibility of allocating only one channel. The necessary change that needs to be done in the core GSM network is the introduction of two new network nodes: the *Serving GPRS Support Node* (SGSN), which plays the role of the MSC/VLR in the GSM network, and the *Gateway GPRS Support Node* (GGSN) which plays the role of the *Gateway* MSC (GMSC) [12]. Additionally, hardware changes need to be carried out on the *Base Station Controller* (BSC) by adding a *Packet Control Unit* (PCU), which processes and routes packet switched data towards the SGSN and base stations (Figure 1).

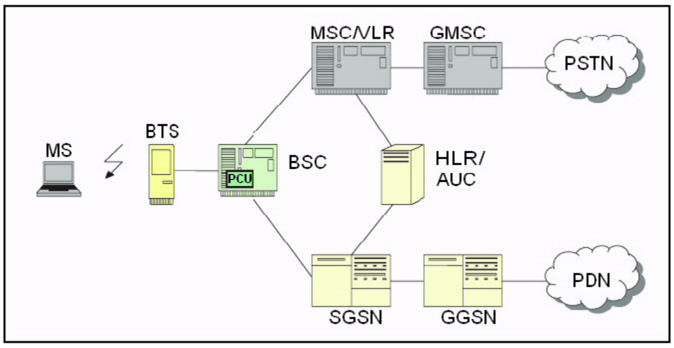

Figure 1. GSM/GPRS network architecture

Current network conditions enable a maximum data rate of 4 x 11.2 kbit/s = 44.8 kbit/s using the CS2 encoding scheme. Limitations are imposed by mobile terminals with maximum *download* capabilities of four *time slots* (four GPRS radio channels). Each channel enables a maximum data rate of 11.2 kbit/s when using current encoding schemes on the radio interface. Additional limitations are due to the fact that most currently available mobile telephones support only one GPRS channel in *upload*. Significantly higher data rates will be enabled in the future by using new encoding schemes (CS3 and CS4) as well as the introduction of *Enhanced Data rates for GSM Evolution* (EDGE), with different modulation methods and more *download* and *upload* channels.

In GSM/GPRS standards [13] the following five QoS parameters are defined:

- **Precedence class** gives the opportunity to the GPRS network to assign different priorities to services, such that in case of congestion, services with a higher priority will receive a better treatment.
- **Delay class** is defined as the end-to-end transfer time between two mobile stations (MS) or between a MS and the Gi interface - interface between Gateway GPRS Support Node and packet data network (PDN).
- **Reliability class** represents the probabilities of loss, duplication, out of sequence and corrupted packets.
- **Mean throughput** defines the mean octet rate per minute measured at the Gi and R interfaces (interface between mobile terminal and terminal equipment).
- **Peak throughput class** defines the peak octet rate per second measured at the Gi and R interfaces

Using different combinations of QoS parameters it is possible to create various QoS profiles for different kinds of end-user applications.

III. NVR Applications Used

Three different applications were selected as case studies as they represent good examples of different types of NVR applications:

- Blaxxun – a multi-user community
- Demy – conversational virtual character
- Unreal – 3D multi-user network game

A. Blaxxun virtual world

The first set of measurements involved a networked collaborative virtual environment (NCVE) built upon Blaxxun's Virtual Worlds Platform (http://www.blaxxun.com) that allows multiple users (*community members*) to meet and interact (Figure 2). Users navigate through various virtual places such as a shopping mall, community square, etc. Client-server architecture is used to distribute information among community members whenever they need updates automatically and in real time. This is necessary for cases such as chat, avatar motion, and shared events/objects.

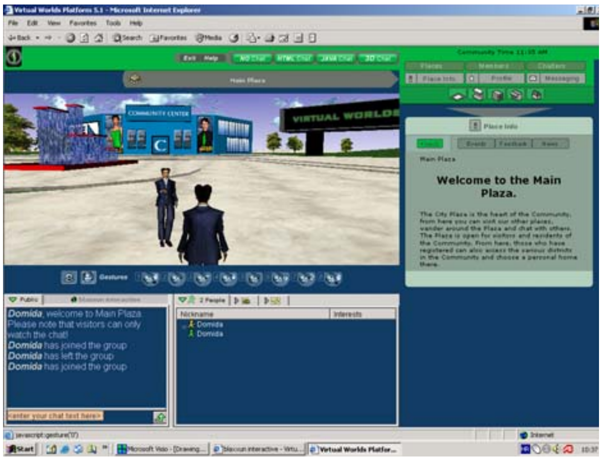

Figure 2. Blaxxun virtual community

B. Demy application

In the second set of measurements, we investigate the QoS requirements of *Demy*, an example of a Web-based virtual character capable of leading a natural language conversation with the user [14]. In general, virtual characters are graphical simulations of real or imaginary persons and may be foreseen as having great potential in areas such as entertainment, commerce, personal communications, and education. In the case of *Demy*, the user downloads a web page (using current versions of Netscape or IE) containing a Java applet displaying the animated VRML character (Demy) and a text box. The virtual character is rendered using *Shout 3D* technology (written in Java), thus eliminating the need for any extra plug-ins or downloads.

When the user types English text in the text box, Demy replies by talking. The artificial intelligence of the virtual character is based on the latest Java implementation of ALICE, which has the name Alicebot.net. ALICE is a "bot", a conversational character. It processes input text and produces answers in the form of text. The answers are based on the "knowledge" which is contained in an Artificial Intelligence Markup Language (AIML) file. This file contains answers to known questions and rules for interpreting users' inputs and providing answers. The animated virtual character (Java applet) can be controlled by JavaScript and instructed to talk. The speech is stored on the standard HTTP server in the form of audio (.wav) files and MPEG-4 lip synchronization files (.fba). These files are streamed on the fly when speech is requested. A special tool to produce lip sync information must be used together with the speech synthesis software.

C. Unreal application

The third set of measurements was performed using *Unreal* – a 3D multi-user network game. The popularity of networked games is expected to scale in the future to possibly thousands of simultaneous end users using various access networks and terminals, showing great perspective for network operators and service providers. Currently, numerous commercial multi-player computer games (e.g. Quake, Unreal) are available that take place in a virtual environment and are therefore considered NVR applications. Requirements on bandwidth depend on the number and distribution of users, along with the applied distribution scheme. Latency requirements depend on the nature of the game, but it is considered that games requiring tight hand-eye motor control, such as first person shooter games (FPS), demand that latency remains less than 100 ms [15].

While there are many similarities between NCVEs (e.g. Blaxxun) and FPS network games (e.g. Unreal), we differentiate these two types of applications since it is apparent that they have different requirements relating to delay. More specifically, the consistency of virtual environment state is much more important in FPS network games than in NCVEs, where the application could still remain usable even with update delays longer than one second.

IV. Environment used for measurements

Measurements were performed on the selected applications in order to evaluate their performance when accessed through a GPRS network. This was done by determining throughput and delay as well as user perceived service quality. For comparison reasons, the same measurements were carried out for Internet/intranet connections as for the GPRS connection.

Figure 3 shows VIPNet GPRS network that was used for performing measurements. The core of the network is made up of Ericsson *Combined* GPRS *Support Node* CGSN-25 and Cisco L3 *switches*. CGSN-25 is an integrated GPRS *Support Node*, i.e. it performs the functions of both the SGSN and GGSN.

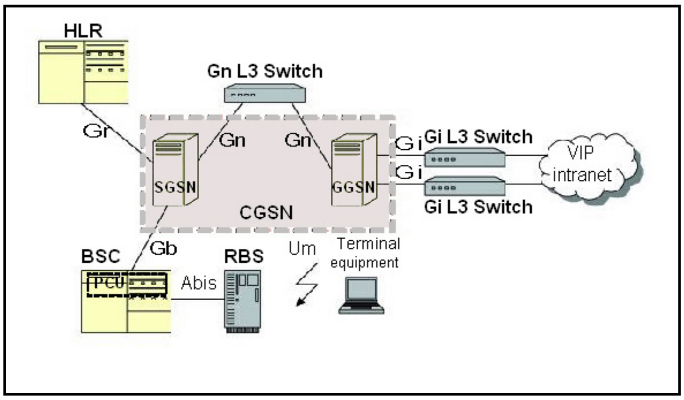

Figure 3. VIPNet's GPRS network

The radio base station used was Ericsson RBS 2102, which can be classified as an Outdoor base station type. It is generally used for testing new software revisions at base stations and MSCs. The RBS 2102 supports a maximum number of six Transceiver Radio Units (TRUs) per cabinet (1 TRU supports eight radio channels, with the possibility of configurations involving one, two or three sectors).

The network environment used for measurements consists of three different parts (Figure 4). The first part is a 10 Mbit/s Ethernet LAN located at the Department of Telecommunications (FER, University of Zagreb) where application servers were situated. The FER LAN is connected to the VIPNet GPRS network by way of the Internet.

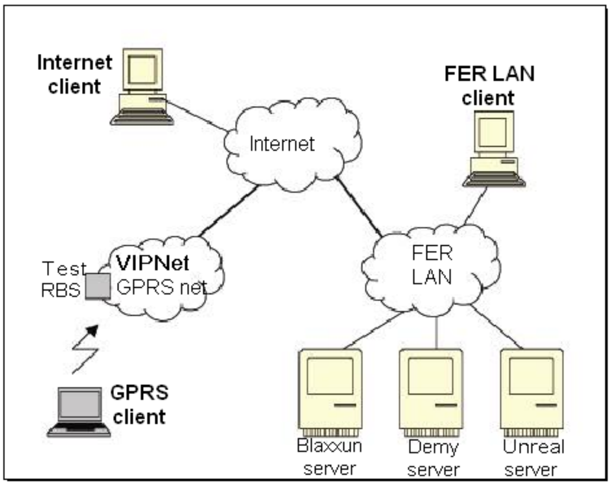

Figure 4. Network environment user for measurements

The conditions on the radio interface between the RBS and the GPRS client were ideal, since the distance between them was about three meters. This minimized the possibility of retransmissions and their influence on delay and throughput.

Three different clients (terminals) are used to access the servers located at FER's LAN. The first client is connected to VIPNet's GPRS network via air interface. The second is connected to FER's LAN (intranet), while the third client accesses the services through the Internet. The terminal configurations used include the following:

- **GPRS terminal:** Pentium II, laptop - IBM ThinkPad (350 MHz, 64 MBRAM) with Windows 98. Additional software: Blaxxun Contact multi-user 3D plug-in. Connected to GPRS network using **Ericsson R520m mobile phone** (three GPRS channels available for *download*, one for *upload*) for *Blaxxun* measurements, and **Ericsson T68i mobile phone** (four GPRS channels available for *download*, one for *upload*) for *Demy* and *Unreal* measurements.
- **Blaxxun server:** Sun Sparc Ultra 5, Sparc v9 (270 MHz, 256 MB RAM) with Solaris 8.0 OS. Additional software: Blaxxun Virtual Worlds Platform 5.1.
- **Unreal server:** Pentium IV (1.6 GHz, 512 MB RAM) with Windows 2000 Professional OS.
- **Demy server:** Pentium IV (1.6 GHz, 512 MB RAM) with Windows XP OS. Additional software: Apache server 1.3.20, Alicebot.net 4.0 beta server.
- **FER LAN terminal:** Pentium III (750 MHz, 256 MB RAM) with Windows 2000 Professional OS. Additional software: Blaxxun Contact multi-user 3D plug-in.
- **Internet terminal:** Pentium III (550 MHz, 128 MB RAM) with Windows NT. Additional software: Blaxxun Contact multi-user 3D plug-in.

In an attempt to simulate "real-world" network conditions (low availability of radio resources, high availability of radio resources), VIPNet's test RBS was used to configure the number of available and occupied channels. In cases when radio channels were occupied, an attempt was made to achieve better service quality by setting various QoS parameters. These parameters are defined in the HLR when a user pays for a certain *Access Point Name* and include the following:

- *Precedence class* (*high, normal, low*): describes the amount of time data is kept in a queue in the GSN node when the queue starts filling up (*high* refers to the longest waiting time in the queue).
- *Delay (high delay, low delay, normal delay, best effort)*: describes maximum network delay allowed when transmitting data. In the case of delay exceeding this value, the connection is terminated.
- *Reliability class* (*class 1 through class 5*): describes the degree of reliability requested when accessing the network.

Measurements were performed using the *NetXray* (http://www.netxray.co.uk) and *Ethereal* (http://www.etheral.com) tools for capturing, filtering, and analyzing network traffic. Graphs depicting network throughput were drawn using *NetXray*.

In the following sections we describe measurement procedures using three different NVR applications, and give an analysis of achieved results.

V. Measurements and Results

A. *Measurements using Blaxxunn virtual world*

1) *Measurements description*

As mentioned earlier, Blaxxun NCVE was used in the first set of measurements to compare its performance when accessed from a GPRS network, FER LAN and Internet.

In order to compare different access networks (Internet, FER's LAN, VIPNet's GPRS network), several characteristic actions were defined:

- Entrance to the NVE – represents the initial access to the NVE. This is the most demanding action since it implies downloading all the data describing the virtual environment.
- Walk in the NVE – movements in the NVE generate new updates, which means that the number of update packets being sent to all community members increases. Although the rate of updates increases, bandwidth utilization remains low due to the fact that the size of update packets is relatively small (around 80 bytes).
- Room change in the NVE – represents moving between rooms in the NVE, which implies downloading a considerable amount of data describing the new room.
- NVE World info use – represents the provision of data about the NVE, community members etc. using objects (terminals) in the NVE. The amount of data transferred is relatively low.

The specified actions require transfer of the same data amount in all environments so they represent good reference to compare different network environments.

Parameters used for comparison are:

- Download throughput (byte/s) for all three clients and for all four characteristic actions in NVE;
- Time necessary to complete a certain action (entrance to the NVE, walk in NVE, room change in NVE, NVE World info use) for all three clients;
- Round-trip time (RTT) for all three terminals.

Measurements were performed on all three clients simultaneously because every client generates traffic, which is sent to all clients in the NVE (different kinds of updates) and decreases available bandwidth of other clients in NVE. Four radio channels on our test RBS were defined as GPRS dedicated channels. Mobile phone used for Blaxxun measurements was Ericsson R520, which supports up to 33.6 kbit/s in download and 11.2 kbit/s in upload.

Three different traffic scenarios were used:

- Low availability of radio resources in the GPRS network – several users were using same radio channels;
- Low availability of radio resources in the GPRS network – several users were using same radio channels but our GPRS terminal had good QoS parameters;
- Good availability of radio resources in the GPRS network – three GPRS radio channels were available (33.6 kbit/s in download).

In the first two traffic scenarios (low availability of radio resources), different QoS profiles were used to achieve better utilization of available bandwidth.

Measurements were performed for all four defined characteristic actions described above. Time for specific action (Entrance to the NVE, Walk in NVE, Room changing in NVE, World info use) for all three clients was determined from throughput graphs. Standard *Ping* program was used to get round-trip time.

a) Low availability of radio resources in the GPRS network (1st measurement)

In this measurement three radio channels were used by another GPRS subscriber performing continuous FTP download. The same QoS parameters were assigned to both that user and the mobile terminal used to connect to the Blaxxun server. In this situation both subscribers should have the same bandwidth available. QoS parameters defined in the HLR for both subscribers were:

- Delay: BEST EFFORT
- Precedence: NORMAL
- Reliability: RELIABILITY CLASS 3 - *Non-real time traffic, for error sensitive applications*

b) Low availability of radio resources in the GPRS network – good QoS parameters (2nd measurement)

In this measurement three radio channels were also used by another GPRS subscriber performing continuous FTP download. However, the mobile terminal used to connect to the Blaxxun server had the following QoS profile:

- Delay: LOW
- Precedence: HIGH
- Reliability: RELIABILITY CLASS 4 - Real time traffic, error sensitive applications

The subscriber performing FTP download had following QoS parameters:

- Delay: NORMAL
- Precedence: NORMAL
- Reliability: RELIABILITY CLASS 3 - Non-real time traffic, for error sensitive applications

c) Good availability of radio resources in the GPRS network (3rd measurement)

In this measurement all GPRS radio channels were available, ensuring download rates of 33.6 kbit/s, so there was no need to set QoS parameters.

2) Results and analysis

As shown in Figure 5 measurements of round-trip times gave very poor results, with an average of approximately 1000 ms. In multi-user interactive virtual environments such as this one, changes resulting from a user's actions need to be made visible to other users in a consistent manner in order to achieve ”real-time” interactivity. Delay is therefore a key factor determining user perceived quality. High delays such as those measured in the GPRS network scenario may therefore be the cause of inconsistencies among users. RTT measured from the Internet terminal resulted in an average of 137 ms, which is low enough to perceive “real-time” interactivity, while LAN measurements showed an average of only 7 ms.

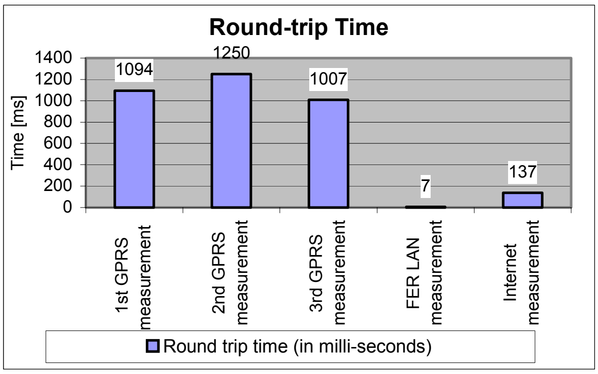

Figure 5. Round-trip time for all three networks and three different GPRS traffic scenarios

Throughput measurements showed that the available bandwidth in the GPRS network might be considered insufficient for performing certain actions in the NCVE. Initial access to the NCVE (Figure 6 and Figure7) requires the transmission of a large amount of data and is the most bandwidth consuming of all the actions that were performed. In the FER LAN (100 Mbit/s), data rates reached up to 400 kbit/s. Data rates measured on the Internet terminal reached up to 150 kbit/s.

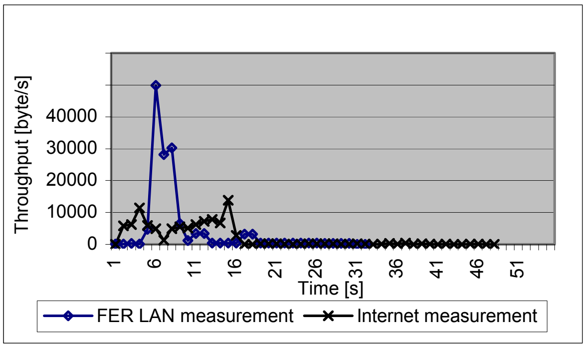

Figure 6. Throughput for “Entrance to the NVE” (download) action (FER LAN and Internet clients)

At the same time, data rates in the GPRS network reached a maximum of 33.6 kbit/s, however due to RTTs, data rates varied even in the case of high availability of radio channels.

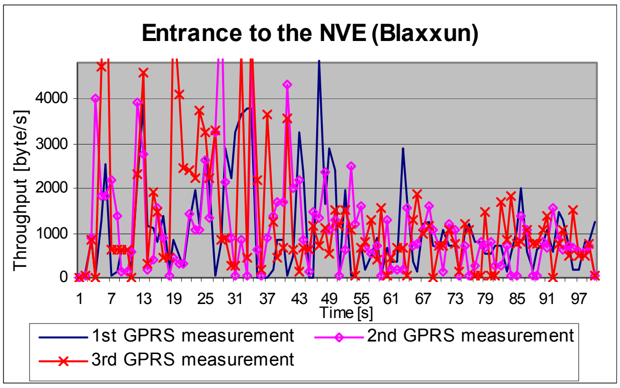

Figure 7. Throughput for “Entrance to the NVE” (download) action (3 GPRS measurement)

Besides initial access to the NCVE, changing a room/place in the community also resulted in the transmission of large data amounts, with data rates in the FER LAN reaching up to 112 kbit/s (Figure 8).

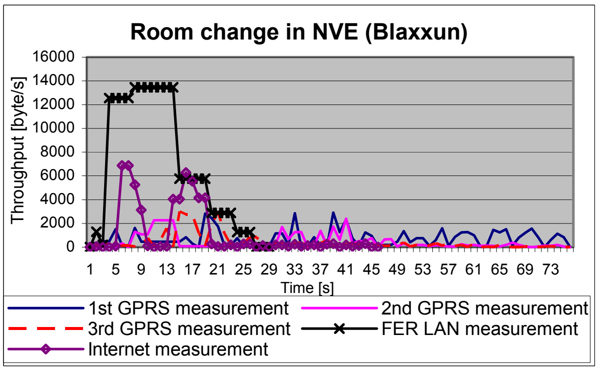

Figure 8. Throughput for “Room change in NVE” action

The actions of walking around in the NCVE (Figure 9) and downloading information about the community proved to be less demanding. In those cases the GPRS network provided sufficient bandwidth.

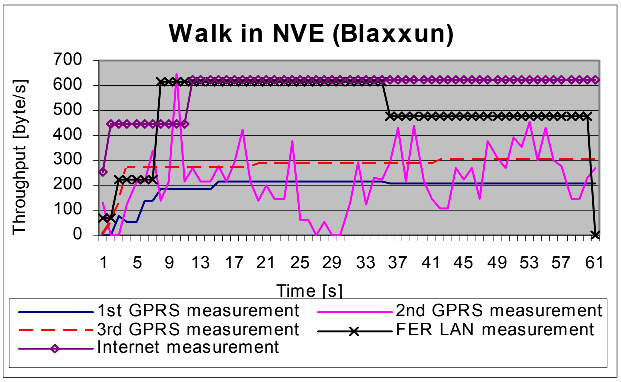

Figure 9. Throughput for “walk in NVE” action

Measurements showing the time necessary for performing a certain action (Figure 10) are probably the best proof of problems relating to bandwidth availability.

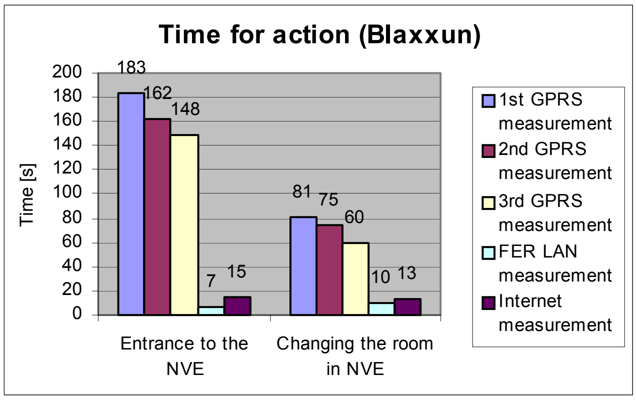

Figure 10. Time for actions “Entrance to the NVE” and “Room change in NVE” for all environments and all traffic cases in GPRS network

Initial access to the NCVE takes approximately 7 s when connected to the FER LAN, 15 s when connected to the Internet, and around 160 s when connected to the GPRS network. Changing a room takes approximately 10 s when connected to the FER LAN, 13 seconds when connected to the Internet, and around 75 s when connected to the GPRS network. Less demanding actions such as requesting community information take approximately the same amount of time in all three cases.

The effects of varying QoS parameters in cases when radio resources are occupied remained practically unnoticed. The reason for this is that the defined parameters have an effect on connection quality when the *GPRS Support Node* (GGSN) becomes congested, while having very little effect on the radio interface. We do, however, see a slight decrease in times necessary for performing certain actions from GPRS measurements 1 through 3. We therefore conclude that this is due to QoS parameters and higher availability of radio resources. Even though measurements were performed in a real GPRS network, load (in the *core network* part) still remains very low. This is also currently the case with most European GSM/GPRS network operators.

B. Demy Application

1) Measurements description

Measurements were performed to determine the time necessary for the virtual character to respond to a question asked by the user (*Time to Answer* - TTA). This involved the generation of a *.wav* file and an *.fba* file on the server side. These files are streamed across the Web to the end user. Measurements of TTA can be found in [14] where tests were performed in a best effort Internet environment. For our purposes, we use the newest available version of Demy to test TTA in a GPRS network environment.

Questions and answers sent to Demy server and received from Demy server were as follows:

- Q: Hello (A: Hi there) – .fba file size = 90 B, .wav file size = 1.83 kB

- Q: How are you? (A: I'm fine. Thank you.) – .fba file size = 153 B, .wav file size = 3.48 kB
- Q: What do you do (A: Human, I talk to the people on the web. What do you do?) – .fba file size = 281 B, .wav file size = 6.97 kB

As mentioned earlier, four GPRS radio channels were available for download (maximum of 44.8 kbit/s) and Ericsson T68i mobile phone was used to connect to the network. The test BSC used offered the possibility of configuring channels as GPRS *dedicated time slots*. Measurements in the GPRS network were conducted under three different network situations using dedicated time slots:

- Low availability of radio resources in GPRS network – only one time slot dedicated to mobile terminal (11.2 kbit/s) in download and upload
- Low availability of radio resources in GPRS network – two time slots dedicated to mobile terminal in download (22.4 kbit/s) and one in upload
- Good availability of radio resources in GPRS network – three time slots dedicated to mobile terminal in download (33.6) and one in upload

TTA was determined from log files made with the Ethereal application.

The QoS parameters investigated in *the first measurement* were not used due to the fact that they had no effect on service quality.

2) Results and analysis

Measurements of Demy application showed results similar to Blaxxun measurements (Figure 11).

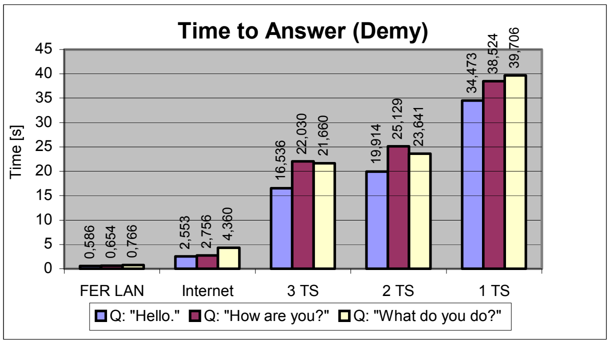

Figure 11. Time To Answer for Demy application

Delays were significantly shorter in FER LAN and in Internet than in GPRS network. TTA in FER LAN is no longer than 1 s, in Internet maximum TTA was 4 s while in GPRS network average TTA was about 25 s. As expected, the measurements showed that TTA decreases when more time slots are available to the mobile terminal. However, the difference between TTA values for two and three time slots measurements are relatively small (when compared to TTA values for one time slot measurements). This is due to the fact that the maximum bandwidth of 22.4 kbit/s (available with two dedicated time slots) is close to the peak value of the throughput used by the application (Figure 12).

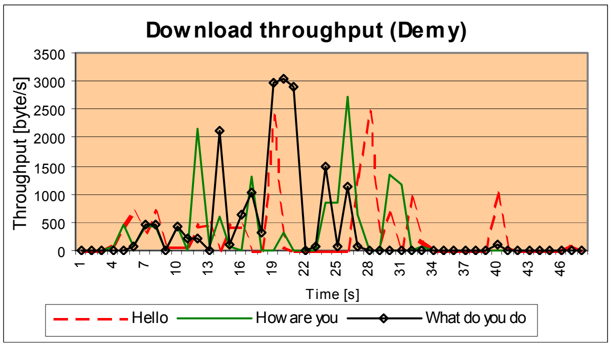

Figure 12. Throughput (in download) for Demy application (three time slots)

Extremely long response times measured in the GPRS network reduce the feeling of “real-time” interactivity. For a practical deployment of this application, we feel that far better results are necessary. A TTA in the range of a few seconds might be considered acceptable.

C. Unreal Application

1) Measurements description

The third set of measurements was performed to investigate the possibility of accessing the popular *Unreal tournament* game using a GPRS terminal. A PC located in the FER LAN network played the role of game server (Figure 4). Two users took part in the game and fought against each other on opposing teams. One user was connected to the FER LAN using a PC, while the other user was connected to the GPRS network using a laptop and Ericsson T68i mobile phone (as explained earlier).

The test RBS was used to dedicate four GPRS radio channels to the GPRS connection (44.8 kbit/s). Two different measurements were performed:

- Measurement of throughput (in download) on the GPRS client
- One-way delay on both sides, Unreal server in FER LAN and GPRS client

Throughput was measured as in two previous measurements (with NetXray application). Ethereal was used to determine one-way delay. Packets were captured on both sides and delay was calculated from packet receive times. This required the synchronization of clocks on both computers, which we accomplished using the program *Yet Another Time Synchronizer* (YATS) 8.1.

2) Results and analysis

Bandwidth measurements (Figure 13) spanning a time period of approximately 5 minutes show a high degree of interactivity throughout the game. Both users saw a smooth picture throughout the game. However, the user connected to the GPRS network complained about consistency problems (not being able to hit the other player when shooting). No such problems were noticeable at the terminal connected to FER LAN. This was obviously due to extremely high delays measured in the GPRS network. In the case of a *real time strategy* (RTS) game, delays are more tolerable. Tests were not repeated with one, two and three dedicated time slots due to the fact that measurements with four time slots already showed extremely poor performance.

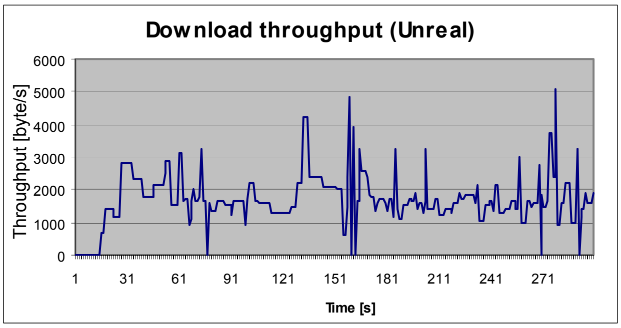

Figure 13. Throughput (in download) for Unreal application

Measurements of average delay are shown in Table 1. The average delay from the GPRS terminal to the game server was measured to be 407 ms greater than from the server to the GPRS terminal.

TABLE I. ONE-WAY DELAY MEASURED FOR UNREAL TOURNAMENT

Direction	Average delay [s]
GPRS terminal to game server	1.407355
Game server to GPRS terminal	1.000209

This was expected due to greater bandwidth availability in the download direction. The high values explain the reasons for consistency problems. The most likely reasons for such high delay values are limited bandwidth, especially in the upload direction with only one channel available, as well as time needed for PCU processing.

VI. CONCLUSION

The measurements performed on three selected applications showed that the capabilities of the present GSM/GPRS networks provide insufficient support. Although one could not generalize these results to cover other applications, low bandwidth availability is a serious limitation. Even greater problem is high delay, caused by low bandwidth and the mechanisms for adaptation of TCP/IP packets to the radio interface, performed by BSC's PCU. In the GPRS network used for measurements, about 70 % of RTT is spent on the conversion of TCP/IP packets to radio block and radio channel allocation. Delays in GPRS networks can also be caused by retransmissions on the RLC/MAC level of the radio interface, but due to the robustness of CS-1 and CS-2 coding schemes, retransmission are very rare (and most often occur at handover). The possibility of retransmissions in our test environment is further minimized by ideal conditions on the radio interface (short distance between the RBS and the GPRS client).

The future of GPRS predicts incorporation of new encoding schemes resulting in data rates of more than 100 kbit/s in download, and also significant increases in the upload direction (compared to today's 11.2 kbit/s). The EDGE (*Enhanced data rates for GSM and TDMA/136 evolution*) radio access network (ERAN) has been designed to handle packet-switched data (GPRS/EDGE) and circuit-switched GSM services. Delays will be reduced (RTTs of 500-600 ms), but will still present a problem for some NVR services.

REFERENCES

[1] M. Matijasevic, I. Lovrek, D. Mikic, A. Caric and D. Huljenic, "Designing Bandwidth-Aware Virtual Reality Services for the New Generation Networks", Proc. 9th Int. Conf. on Telecommunication Systems, Modeling and Analysis, Dallas, TX, March 2001, pp. 84-89.

[2] M.R. Macedonia and M.J.Zyda, "A Taxonomy for Networked Virtual Environments", IEEE Multimedia, Vol. 4, No. 1, Jan.-Mar. 1997, pp.48-56.

[3] K.S. Park and R.V. Kenyon, "Effects of Network Characteristics on Human Performance in a Collaborative Virtual Environment", Proceedings of IEEE VR `99, Houston, TX, March 1999, pp. 104-111

[4] K. Jeffay, T. Hudson and M. Parris, "Beyond Audio and Video: Multimedia support for Distributed Immersive Virtual Environments", Euromicro, September 2001, pp. 300-307

[5] L. Skorin-Kapov, D. Vilendecic and D. Mikic, "Experimental Performance Evaluation of Networked Virtual Reality Services", Proc. of MIPRO, Opatia, Croatia, May 2002, pp. 76-81.

[6] G. Karagiannis and G. Heijenk, "QoS in GPRS", Ericsson technical report EMN 5/0362-FCP NB 102 88 Uen, December. 2000.

[7] Ch. Lindemann and A. Thümmler, "Evaluating the GPRS Radio Interface for Different Quality of Service Profiles" 12th GI/ITG Fachtagung Kommunikation in Verteilten Systemen (KiVS), Hamburg, Germany, pp. 291-301, Springer-Verlag, Feb. 2001.

[8] T. Irnich and P. Stuckmann, "Analitical Performance Evaluation of Internet Access Over GPRS and Its Comparison with Simulation Results", Proc. of the 13th Intl. Symposium on Personal Indoor and Mobile Radio Communication 2002 (PIMRC), Lisbon (Portugal), Sept. 2002.

[9] R. Chakravorty and I. Pratt, "WWW Performance over GPRS", in IEEE Intl. Conf. on Mobile and Wireless Communication Networks (MWCN2002), Stockhholm, Sweden.

[10] R. Chakravorty, J. Cartwright and I. Pratt, "Practical Experience with TCP over GPRS, Proc. of the IEEE GLOBECOM 2002.

[11] M. Oliver, B. Bellalta and D. Rincón, "Traffic analysis and capacity for VoIP services over GPRS mobile networks", Proc. Of Regional Intl. Teletrafic Seminar (LONIIS) p. 64 – 73, January 2002, St. Petersburg (Russia).

[12] C. Bettstetter, H.-J. Vögel and J. Eberspächer, "GSM Phase 2+ General Packet Radio Service: Architecture, Protocols and Air Interface", IEEE Communications Surveys, Special Issue on Packet Radio Networks, vol. 2, no. 3, Third Quarter 1999.

[13] Digital Cellular Telecommunication System (Phase 2+); General Packet Radio Service (GPRS); Service Description; Stage 2 (3GPP TS 03.60 version 6.9.0 Release 1997)

[14] I.S. Pandzic and R. Forchheimer (editors), MPEG-4 Facial Animation Framework for the Web and Mobile Platforms in "MPEG-4 Facial Animation - The standard, implementations and applications". John Wiley & Sons, 2002, ISBN 0-470-84465-5.

[15] J. Smed, T. Kaukoranta, H. Hakonen. Aspects of Networking in Multiplayer Computer Games. Proc. of Intl. Conf. on Application And Development of Computer Games in the 21st Century, 2001.