# Player Experience and Technical Performance Prospects for Distributed 3D Gaming in Private and Public Settings

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Distributed gaming enables access to interactive media from devices based on different platforms. It facilitates users to enjoy video games in various environments without the need for using a single device or operating system. Understanding the potential and limitations of such gaming-on-demand systems is key for their adoption and further growth in public places. This paper presents an in-depth, quantitative study performed with the Games@Large (GaL) distributed-gaming system and its potential users at an Internet café in Genoa, Italy. The approach of the study was multilevel, covering the player experience and user acceptance aspects as well as technical performance peculiarities. Results show that the GaL system has a high potential at Internet cafes, in particular when playing a casual genre game. Furthermore, results provide recommendations for deploying such systems in terms of social setting and technical aspects. The methodology and findings of the GaL system tests can be applied to similar game streaming systems and used as input for theories on social digital game play.

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## 1. INTRODUCTION

The Games@Large (GaL) project has developed a novel, distributed 3D gaming system [Tzruya et al. 2006], both for homes and enterprise public environments, like hotels, Internet cafés, and senior housing complexes. GaL's innovative architecture, transparent to legacy game code, allows distribution of cross-platform gaming on a variety of low-cost networked devices. It enables Personal Computer (PC) game play on low-cost Consumer Electronics (CE) devices without the need for game software modification. In comparison to other currently emerging systems, that were overviewed in [Jurge-lionis et al. 2009], the GaL framework explicitly addresses support of end-devices with different characteristics, ranging from PCs running different operating systems to Set-Top Boxes (STB) and to simple handheld devices with small displays and relatively slow Central Processing Units (CPUs). By virtually extending the capabilities of such devices through exploiting adaptive streaming techniques, the GaL system is opening important opportunities for new services and experiences in a variety of fields, in particular for pervasive entertainment at home and in public environments.

To increase the market success of a product, it is vital to iteratively design and evaluate it with a wide range of potential end-users before it is released. Usability and technical tests provide a rich and large amount of input for improving the design of the system's usability and overall performance. In the case of a gaming system, like GaL, it is also vital to gather an understanding of GaL's player experience within different user groups at different locations. Important topics emerging from these investigations relate to the GaL service and interesting additional features, in particular concerning social play, information and communication needs, player experience, and system performance prospects in public places. A number of iterative design cycles have already been performed with end-users during the GaL project [Martins et al. 2010]. The work presented in this article focuses on the final Beta-tests of GaL performed at an Internet café in Genoa, Italy. It is organized as follows: Section 2 outlines the GaL system and the Internet café environment in more detail; Section 3 gives an overview of related research papers used as a point of departure for our study; Section 4 presents the research goals and rationale of the study; Section 5 describes the test site and related procedural components, such as test site location, testbed, procedures, participants, questionnaires, and technical measurements; Section 6 reports the results of the tests; Section 7 presents the discussion; and finally Section 8 concludes the article.

## 2. THE CONTEXT

In this section, we describe the gaming system evaluated in this article as well as the context of the evaluation.

#### 2.1. Games@Large Distributed 3D Gaming System

The GaL framework [Tzruya et al. 2006] depicted in Figure 1 enables cross-platform streaming of video games from a PC to other computers and mobile and consumer electronics devices in homes and other environments such as hotels, internet cafés, and senior housing complexes. A central PC is utilized to execute multiple games and streams them with a high visual quality to multiple concurrently connected clients via a wireless/wired local area network (LAN) supporting Wi-Fi Multimedia Quality of Service (WMM QoS) [Jurgelionis et al. 2009].

The GaL framework consists of the following components.

Server Side. A Windows PC with the Local Processing Server (LPS) running games from the Local Storage Server (LSS) and streaming them to clients. The LPS is responsible for launching the game process after client-side invocation as well as managing execution of multiple games. It performs capturing of the game graphic commands for



Fig. 1. GaL framework.

3D streaming or, alternatively, already rendered frame buffers for video encoding. It also captures and encodes the game audio. Consequently, it performs real-time streaming of the resulting audio-visual data. The LPS is further responsible for receiving the game controller commands from the end device and injecting them into the game process.

*Client Side.* The client module, running on a Windows/Linux PC or notebook, a WinCE/Linux STB, or a Linux-based handheld device, receives the 3D graphic command stream and executes the local rendering using OpenGL. For the video streaming approach, H.264 decoding must be supported. The client is also responsible for capturing the controller commands (e.g., keyboard or gamepad) and transmitting them to the processing server [Nave et al. 2008].

3D Streaming. A state-of-the-art graphics streaming protocol [Jurgelionis et al. 2009; Nave et al. 2008] is used for streaming 3D commands to end devices allowing lower performance devices such as interactive TV STBs to display high-performance 3D applications, such as games, without the need to actually execute the games locally.

*Video Streaming.* An alternative video-streaming approach has been developed, because the 3D graphics streaming approach cannot be used for several mobile devices that lack the hardware capability for accelerated rendering. Synchronization and transmission are realized via User Datagram Protocol (UDP)-based Real-Time Protocol /Real-Time Transport Control Protocol (RTP/RTCP) in a standard compliant way. High Efficiency Advanced Audio Coding (HE-AACv2) is used for the audio streaming [MPEG-4 2005].

*Networking.* The network connection to the game client may consist of both wired and wireless links. To ensure smooth game play, sufficient bandwidth and low-enough latency are required from the wireless home network. In order to meet the requirement of using low-cost components, the choice for the wireless home network has been to use IEEE 802.11-based technologies, because of their dominant position in the market. Priority-based QoS is supported using Wi-Fi Multimedia (WMM) extensions at the Medium Access Control-Layer (MAC-Layer) and UPnP QoS framework for QoS management.

Different end devices typically provide several different input modalities. In the initial discovery phase performed by the Universal Plug and Play (UPnP) device discovery, the end device sends its properties and capabilities. During the game play, the input from the controllers is captured either using interrupts or through polling. The

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	User and context characterization	User-centered/technical research foci
Internet Café	General public, typically youngsters. Groups of friends, who usually do not socialize with others. The network is highly dynamic, and visitors may use a variety of devices, from cell phones to TV screens, from laptops to wide screens.	Support for socialization within groups of friends and among them. Customer ties and community building. Multiplayer games supported.

Table I. User-Centerd/Technical Research Foci for Internet Café

captured commands are then transmitted to the server. At the server side, the input commands are mapped to the appropriate game control and injected in real time into the game instance running at the server.

There are two editions of the GaL platform: (1) Home edition, intended for deployment at people's homes; and (2) Enterprise edition, intended for deployment at Internet cafés, hotels, and senior housing environments.

The Home edition of the GaL platform has no billing, generic user authentication (parental control requirements make authentication necessary), and includes a simple, lightweight database with no Database Management System (DBMS), but rather a simple file structure accessed by specific drivers. The objective is to have the ability to utilize the power and resources of an existing home PC in order to serve games without distracting any other user that is using the same PC at the same time.

The Enterprise edition consists of a LMS, one or more LPSs, and one or more LSSs. It includes user authentication, a sophisticated database system, billing, and an administration system. It is designed for use at enterprise environments with large number of users.

### 2.2. Internet Café – Public Setting

The Internet café is one potential market for game players [Gajadhar et al. 2009]. There are two different types of Internet cafés, each one with a different audience.

The first is the Internet café, which frequently does not have desktop devices. The Starbucks café chain is, in fact, the largest Internet café chain in Europe, through their ubiquitous wireless Internet provision, and in spite of not being advertised as an "Internet café" [Salvador et al. 2005]. It may function as a work place as well as a game environment.

The other type of Internet café is the game parlor, which typically has high-end desktop terminals, and is designed primarily for online game play, not for general Internet access as such. Game parlors are environments where people gather in a face-to-face and mediated environment to play online games, video chat, and meet others [Gajadhar et al. 2009]. Korea, in particular, has seen rapid growth of these parlors, known as "PC bangs" [Salvador et al. 2005]. These rooms are social environments where virtual and physical realities are not mutually exclusive. In fact, "love seats," originally installed for couples to use together, have turned into an Internet-mediated bar stool where video chatters can arrange to meet and interact online in close physical proximity [Freeman et al. 2009].

The study presented in this article focuses on the first type of Internet Café, featuring the characteristics and research foci described in Table I.

## 3. RELATED WORK

Gaming at Internet cafés and other public places is a relatively scarcely studied subject and usually features a survey type of research. There has been relatively little focus on game cafés in Western Europe [Gajadhar et al. 2009] compared to studies of game cafés in Asia [Jonsson 2010; Rangaswamy 2007]. In general, some publications argue its importance. For instance, Kolko and Putnam [2009] present the results of qualitative and quantitative work spanning eight years of investigation in Central Asia focused on computer gaming in public Internet cafés as well as private spaces. Another study shows that gaming is increasingly popular in the Internet cafés in Toronto [Middleton 2003]. A Human Rights in China (HRIC) field survey [HRIC 2005] presents relevant findings on China Internet cafés and shows that a primary use for Internet cafés, and the source of much of their clientele, is gaming, particularly online MMORPGs (Massively Multi-player Online Role-playing Games). In Western Europe, game cafés can be seen as a third place, as they are environments where people go to relax, be entertained, and socialize, aside from the home, work, and school environments [Gajadhar et al. 2009].

Many studies report that people enjoy playing digital games together or watching others play, as players can demonstrate their skills and enjoy the feedback of enthusiastic bystanders [de Kort and IJsselsteijn 2008]. A recent field study [Gajadhar et al. 2009] revealed that playing together online or in colocated settings provides gamers the feeling of inclusiveness and belonging to a group, that is, social connectedness. This social function is suggested as the key factor that affects the motivation for a player's choice of coplay setting. In line with Jans and Martens [2005], the study further revealed that social interaction and social competition are among the main motivations to engage young adults in digital gaming. A subsequent study [Gajadhar 2008a, 2009a] was conducted to empirically test the role of social interaction and competition-on-player experience. An experiment was performed where participants played a digital game in three types of coplay configurations: virtual, mediated, and colocated [Gajadhar 2008b]. A Game Experience Questionnaire [IJsselsteijn et al. 2008] was applied in the study and results indicated that playing side-by-side significantly adds to fun, challenge, subjected competence, flow, boredom, and immersion in the game as compared to playing against a distant or virtual opponent. For most game experience components, the effect of social context was mediated by the level of social presence, which was measured with the Social Presence in Gaming Questionnaire (SPGQ) [de Kort et al. 2007]. Furthermore, player experience-in terms of positive affect, competence, challenge, frustration, and flow—was significantly influenced by players' in-game performance (i.e., winning or losing). A subsequent study [Gajadhar et al. 2009b] investigated why colocated coplay was more positively experienced than mediated play. Since it was hypothesized that social interaction shapes player experience, the influence of additional social communication channels-such as webcams and headsets-on player experience and social presence was tested. The data revealed that player experience components were significantly influenced by the availability of social cues, especially by talking, making exclamations, and laughing. Analyses revealed that the level of social presence depended on the availability of audio cues in digital game settings. Again, in-game achievements appeared to be very important for players' in-game experience. These findings illustrate that social context is an important determinant of player experience in digital games, especially when there is room for conversation (which also is often the case in Internet cafés). By applying the SPGQ [de Kort and IJsselsteijn 2008; IJsselsteijn et al. 2008], differences in most player experience components were explained by the feelings of social presence. The methods and analyses in these studies provided a clear view of how player experience can be affected by the context. However, besides the social context, effects can also result from the media context. For instance, the performance effects of the GaL system and its components (e.g., 3D streaming software, network) on player experience were demonstrated in Jurgelionis et al. [2010] and Korobkin et al. [2009]. The latter conducted an explicit analysis of the effects of latency and jitter; Jurgelionis et al. [2010] stress the importance of the multilevel testing methodology, which is based on user

assessment and technical measures for the system under development. The benefits of the multilevel approach were demonstrated in a real case where a design weakness was discovered during the testing process and addressed in the protocol development. In similar fashion, the effects of networking, frame rate and resolution on player experience in online games were studied in Svoboda and Rupp [2005], Korobkin et al. [2009], Beigbeder et al. [2004], Dick et al. [2005], and Claypool and Claypool [2007].

In general, these studies are based on the player experience framework presented by de Kort and IJsselsteijn [2008], which theorizes that social characteristics of play settings are highly important for player experience. The framework was partly based on field studies in the FUGA project [FUGA 2011]. Here, player experience data of about 400 players was gathered per game genre, platform, etc. The data is highly useful to compare or benchmark the player experience of the user groups in the Beta-tests, especially since it is includes player experience data from many game genres: First Person Shooters (FPS), Role Playing Games (RPG), Sports/Racing Games, Puzzle & Quiz Games, Action Adventures, and Strategy Games. The GaL games that were made available for the Beta-evaluations are mainly in the casual game genre; therefore, the FUGA data of the Puzzle & Quiz games seem useful to benchmark the GaL Beta-player experience.

In sum, we argue that the methodologies used and findings of the aforementioned studies can be used to study the performance of the GaL devices.

#### 4. RATIONALE AND GOALS

The main goal for the Beta-tests at Internet cafés was to study the PC GaL Beta enddevice. The focus was on the user acceptance and on the player experience of the GaL solution in situ. Two different studies were planned.

First, a quantitative player experience comparison study of a wireless versus wired setup of the GaL Beta system, and a comparison was made between private and public play. The rationale for studying wireless versus wired was given by the lack of player experience data about how wireless distributed 3D game streaming performs compared to wired streaming. A wireless network is preferred for a public setting, because no hard-wired network infrastructure has to be set up; i.e., a wireless network is more efficient in terms of time and money to set up and maintain compared to a wired network. As reported in Section 1.2 (Table I), Internet café visitors were characterized as groups of friends, but groups that usually do not socialize with each other. It is interesting to gather an understanding about the player experience of visitors while playing in public or private settings, in particular when they are strangers to each other. These insights could be valuable to Internet cafés for the design of private or public places for digital Game play.

Second, a QoS quantitative player-experience comparison was made of a wireless vs. wired setup of the GaL Beta system for the public play setting and in the presence of additional traffic in the WLAN. This study was similar to the previous one, with the focus on the player experience of visitors while playing in a public setting. Other wireless devices in the same wireless network and neighbouring wireless networks could interfere with the GaL data stream. Our unanswered research question was understanding the extent to which the interference in a natural setting of an Internet café influences the player experience.

Finally, beside the player-experience data, systems' technical data were gathered by means of network traffic and device performance measurements to compare the measured data versus the player experience results and identify which components of the GaL framework influence the performance of the system. Player Experience and Technical Performance Prospects for 3D Gaming



Fig. 2. GaL test site: Mentelocale Intenet Café at Palazzo Ducale in Genoa, Italy.



Fig. 3. Setup for the quantitative study at Mentelocale Internet café in (a) a private setting and (b) a public setting.

## 5. TEST PREPARATION

This section describes the preparation we made before conducting the tests.

### 5.1. Test site and Testbed

The GaL system was deployed in the Mentelocale Internet café in Genoa, Italy. Mentelocale is situated in the very center of the city of Genoa, inside Palazzo Ducale, formerly the Doge's Palace, now cultural center for expositions and major events, (see Figure 2). It has a 100 place-covered decors and two inner rooms (of 40 and 15 places). Open seven days a week, it serves lunches and dinners and is a common venue for meetings and presentations. On average, 250.000 people pass by the café and restaurant every year. Daily, from 20 to 50 people connect to the Internet from Mentelocale Café Ducale, with peaks in the afternoon and during the morning. Clients are people from their early 20s up to early their 50s y. Typically, there can be at most four to five clients using the Internet simultaneously. Mentelocale is covered with free WiFi connection powered by "Digital Citizen" AP network; with the same coupon, it is possible to use the web almost everywhere in the center of the city.

There were two client PCs and a single server PC installed at the Internet café test site. The two PCs were separated by means of a screen for the private-play condition (Figure 3(a)) and without a screen for the public condition (Figure 3(b)).

The server installation included the complete GaL Enterprise software, namely the LPS, the LMS, and the LSS. The client installation included the GaL client software on both of the client PCs. Client1 PC was connected to the Games@Large server using Ethernet TX/1000Base-T cable via the 3Com Gigabit network switch and Client2 PC

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			•		
	GaL	GaL	GaL	Wireless Access	Network
	Server	Client1	Client2	Point (AP)	Switch
OS	Windows XP	Windows XP	Windows XP	3Com Office	Fon La Fonera+
	(SP3)	(SP3)	(SP3)	Connect Gigabit	(FON 2201): 8 ×
CPU	Intel Core 2	Intel Dual-Core,	Intel Dual-Core,	Switch: IEEE	Network - Ethernet
	Duo, 3.16 GHz	2.93 GHz	2.93 GHz	801.11g, WMM,	10Base-T/100Base-
RAM	3.5 GB	3 GB	3 GB	$2  imes  ext{Ethernet}$	TX/1000Base-T -
Audio	Realtek HD	Realtek ALC	Realtek ALC	10Base-	RJ-45
		888	888	T/100Base-	
Video	ATI RADEON	ATI RADEON	ATI RADEON	TX/100Base-T -	
	HD5570	HD5570	HD5570	RJ-45	
NIC	10/100/1000 Mbps		WiFi,		
	_		802.11b/g/n,		
			WMM Capable		
Monitor	a 17" Widescreen LCD			1	

Table II. Hardware Specifications



Fig. 4. GaL testbed.

using 802.11b/g/n Wi-Fi via the Fon La Fonera+ (FON 2201) wireless access point. (See Figure 4). The GaL Quality of Service (QoS) traffic prioritization system was enabled in order to achieve a better player experience in the presence of cross traffic.

Seventeen different PC games were installed on the GaL sever. The game "Sprill" by ALAWAR Entertainment, was played during the game-play task. Other games were used for qualitative tests, which are not covered in this article. We selected Sprill because we had Sprill player-experience data from the Alpha studies and not from the other games offered in Beta.

The specifications of the GaL system devices are given in Table II. Notebook (NB) clients simultaneously using the Internet in the same Wireless Local Area Network (WLAN) are labeled as "NB" in Table II. These additional NBs were browsing the Internet, watching YouTube videos and downloading files only during the QoS quantitative tests. Their cross traffic was directly interfering with the GaL game stream.

Some basic functionality tests were conducted on each of the client PCs in order to verify that each of the installed games was working properly and could be used without any problems that might disrupt a normal game play.

A PRTG Network Monitor [Paessler 2011] software was installed on the GaL server in order to monitor device and network performance parameters via the Simple Network

Table III. Test Participants and Duration					
Test	Number of participants	Total duration			
Quantitative study	24 (12M/12F)	3 days			
QoS quantitative study	12 (5M/7F)	1 day			





(a)

(b)

Fig. 5. Games@Large system setup at Mentelocale.

Management Protocol/Windows Management Instrumentation SNMP/WMI queries. For this purpose, all the GaL devices were SNMP/WMI enabled, using Windows Management and Monitoring Tools. A Wireshark network protocol analyzer [Wireshark 2011] was installed on the GaL server, for the QoS functionality testing. The GaL setup for the qualitative and quantitative studies at Mentelocale is shown in Figure 5(a) and (b)—GaL clients' location beside the outer decor).

### 5.2. Participants

Twenty-four participants ( $M_{age} = 28.8$ ,  $SD_{age} = 5.7$ , 12 Female), all regular Internet café visitors, were invited to participate in the quantitative studies at Mentelocale. (See Table III). Five of the participants had never played digital games before, ten seldom played games, one a couple of times a year, two used to play games every month, five every week, and one used to play play digital games every day. Three of the participants used the Internet on a weekly basis and the rest on a daily basis.

Twelve participants from the previous group ( $M_{age} = 29.3$ ,  $SD_{age} = 4.5$ , 7 Female) were invited for the QoS quantitative study (Table III).

### 5.3. Measurements

The study was multilevel and involved two kinds of measurements, player-related and technical.

Player experience was measured by the Game Experience Questionnaire (GEQ) [IJsselsteijn et al. 2008A]. In addition to the player-experience components, playability, perceived control, and perceived image and audio quality were also measured. These measurements are particularly valuable in studing how the performance of the wireless GaL stream scales, according to users' perceptions compared to the wired stream.

GEQ-Positive Affect had a Cronbach's alpha<sup>1</sup> reliability ranging from .47 to .82. GEQ-Competence had a Cronbach's alpha ranging from .69 to .83, GEQ-Challenge an

<sup>&</sup>lt;sup>1</sup>A Cronbach's Alpha is used to measure the internal consistency reliability of the used questionnaire. A reliability of .70 or higher is considered good, .6 or higher as acceptable. Results on the scales with low internal consistencies should be regarded with scrutiny.

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Semi-counte	erbalanced order of the conditions	
Group 1 =	PC Wired - with screen (private)	PC Wireless - with screen (private)
Group 2 =	PC Wireless - with screen (private)	PC Wired - with screen (private)
Group 3 =	PC Wired - without screen (public)	PC Wireless - without screen (public)
Group 4 =	PC Wireless - without screen (public)	PC Wired - without screen (public)

Table IV. Experimental Design of User Testing with the Internet Café Visitors

alpha of .38 to .66, and GEQ-Frustration had an alpha ranging from .60 to .98. GEQboredom had a Cronbach's alpha from .35 to .78; GEQ-Immersion had an alpha range from .43 to .83, and GEQ-Flow an alpha ranging from .81 to .92. The scale perceived control had a Cronbach's alpha ranging from .76 to .89.

Technical performance was measured by the PRTG Network Monitor. Monitored parameters include CPU, RAM, and bandwidth usage for the GaL server and clients, game process memory usage on the GaL server, and PING (Internet Control Message Protocol, ICMP) between the GaL server and the two GaL clients. Additionally, the memory usage of the GaL-related process on the GaL server and client machines was measured. PING measurements were configured as follows: timeout, 1sec; packet size, 32Bytes; PING count, 10 (per query). Query interval was set to 1sec for PING measurements and to 5sec for all the other monitored parameters.

#### 5.4. Procedures

For each of the two studies, two researchers were always present at the test site during the test execution. The first, who had been trained to conduct the described user studies, was responsible for the test procedure execution. The second was responsible for the coordination of the tests and for providing technical support in the case of any technical difficulty or malfunction related to the GaL and performance monitoring systems. All the questionnaires were administered on paper.

The participants played Sprill on the PC twice, once wired and once wireless (counterbalanced) and either with or without a screen in between, i.e., in a public or private setting. (See Table IV).

Participants were recruited via flyers, posters, the Mentelocale website, and at the front desk of the café. Participants were welcomed with coffee or tea. A five-minute introduction was given by the researchers to introduce the GaL system under study and provide information about the test procedure. The participants were assigned to one of four experimental groups (conditions) to minimize carryover effects. The order of the assignment was counterbalanced. A maximum of two people could participate during a session since there were two end-devices, one wired and one wireless (See Figure 2).

After this, participants were asked to read and sign an informed consent form. The informed consent stated what was being studied, ensured anonymous analysis, announced that audio and image recordings were going to be made (if participants agreed to this), and made clear to the participants that they could withdraw their consent and cooperation at any point in time, during or after the test. After the informed consent was signed, a questionnaire was given to gather demographic characteristics. Participants performed the same game play task on the wired and wireless setup, with or without a screen in between. The game and its controls were introduced in the beginning. Then, they started the game. The predefined task lasted for five minutes and always started at the first level of Sprill. Participants were instructed to win as many points as possible, and, after that, they filled in a paper version of the GEQ.

While participants filled in the GEQ, the researcher wrote down their score, terminated the game, and reset the game to level 1 for the next session. Then, participants switched between settings, performed the same Sprill task, and filled in the GEQ. See Player Experience and Technical Performance Prospects for 3D Gaming



Fig. 6. Test procedure block diagram.

Figure 6. The in-game scores were recorded for each participant. Device and network performance parameters were continuously monitored for all the test sessions. (See the block on the right in Figure 6.)

### 6. RESULTS

This section presents the results from the Beta-tests of the GaL system.

### 6.1. User Evaluation

Linear Mixed Models Analyses (LMMA) were performed on each player-experience component with data stream (wireless versus wired) as within groups factor, setting (public versus private) as between groups factor, and participant number as random factor.

6.1.1. Playability, Perceived Image & Sound Quality, and Perceived Control. A significant main effect was found for setting on playability (F(1,44.00) = 4.22; p = .046), yet no significant main effect was found for data stream on Playability (F(1,44.00) = 1.30; p = .260).

Contrast analyses revealed that playability in the private setting was significantly higher  $(M = 4.75 \ (0.4)^2)$  than in the public setting  $(M = 4.38 \ (0.8))$ .

No significant main effects were found for setting or data stream on image quality (Data Stream - F(1,44.00) = .23; p = .636; Setting - (F(1,44.00) = .63; p = .431)), sound quality (data stream - F(1,36.14) = .09; p = .763; Setting - (F(1,38.04) = 1.59; p = .215)), and perceived control (data stream - F(1,35.17) = .55; p = .462; setting - (F(1,38.75) = .35; p = .556)). The means per setting are shown in Figure 7 and the means per data stream in Figure 8.

6.1.2. Player Experience. A significant main effect was found for setting on competence (F(1,36.27) = 6.92; p = .012). Contrast analyses revealed that competence in the private setting was significantly higher (M = 3.5 (1.2)) than in the public setting (M = 3.02)

<sup>&</sup>lt;sup>2</sup>Standard Error (SE) between brackets.

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Fig. 7. Mean Playability, Perceived Image and Sound Quality, and Perceived Control by setting (Public versus Private) at the Internet café (+/-2 SE).



Fig. 8. Mean Playability, Perceived Image and Sound Quality, and Perceived Control by data stream (LAN versus Wi-Fi) at the Internet café (+/-2 SE).

(1.1)). The player-experience components differ significantly between both settings and are depicted in Figure 9.

The main effect of setting on positive affect approached significance (F(1,35.72) = 3.76; p = .061) – positive affect was higher in the private setting (M = 3.54 (1.4)) than in the public setting (M = 3.31 (0.9)).

In addition, a significant main effect was found for setting on immersion (F(1,35.78) = 7.44; p = .010) and on flow (F(1,35.18) = 26.22; p = .000). Contrast analysis revealed that immersion in the private setting was significantly higher (M = 2.46 (1.1)) than in the public setting (M = 2.02 (0.9)), and flow was also significantly higher in the private setting (M = 3.47 (1.5)) than in the public setting (M = 2.81 (1.2)).

No significant main effects were found for setting on frustration (F(1,44.00) = 1.00; p = .323) or challenge (F(1,36.13) = .72; p = .402).



Fig. 9. Mean Player Experience with Error Bars per Setting (Public versus Private).



Fig. 10. Significant differences on player experience between the Benchmark and the PC at the Internet café (+/-2 SE).

Finally, a significant main effect was found for setting on boredom (F(1,44.00) = 4.26; p = .045). Digital game play in the private setting was reported to be significantly less boring (M = 1.31 (0.8)) than in the public setting (M = 1.77 (0.8)).

No significant main effects were found for data stream on any of the player experience components (all F < 1).

6.1.3. Player Experience versus Benchmark. Again, LMMA's were performed on the player experience components, with Study as a between groups factor, and Participant Number as random factor.

Significant main effects were found on immersion (F(1,35.97) = 7.51; p = .009), flow (F(1,37.39) = 7.99; p = .008), and boredom (F(1,91.00) = 8.09; p = .005). Immersion and flow were both significantly higher than the benchmark, and boredom significantly lower. (see Figure 10.)



Fig. 11. CPU usage: (a) Average total CPU usage, (b) Average Sprill game server process and Client process CPU usage.



Fig. 12. Available RAM: (a) Average available memory, (b) Sprill game server process and Client process average working set.

### 6.2. System Performance Evaluation

Total average and percentile results were calculated for each of the monitored parameters. Percentile average was calculated according to the following definitions.

- (1) 95th percentile.
- (2) The averaging interval used for percentile calculation in seconds was 300. Fiveminute averages were used for the calculation.
- (3) Continuous percentile was used to interpolate between discrete values.

Continuous percentile basically means that the measurements are treated as a statistical population and the value is determined by interpolating a value when it is not present. This means that values are interpolated between actual measurements that are varying around the "perfect" center of the measurements [Paessler PRTG7 2011].

6.2.1. CPU and Memory Usage. CPU usage (Figure 11(a)) on the GaL server running two concurrent processes of Sprill is 67% on average. Average free available memory is  $\sim$ 70%, as shown in Figure 12(a). Thus, on the server side, the main load of the GaL system concentrated on the CPU, while RAM it is not a limitation.

Two concurrent Sprill game processes require  $\sim 57\%$  of the two core CPU power and 350MB of RAM (Figure 11(b) and Figure 12(b)), which suggests that the server could execute additional (one or two) concurrent game processes with similar CPU requirements. Indeed, separately from the tests described in this article, a simple stress test was performed on the GaL server. During the 30-minute test, the GaL server was successfully serving four concurrently connected client devices, three of which were PCs connected via an Ethernet switch and running Sprill, and the fourth client device was a notebook connected via a wireless access point and running "10 Talismans," a game by Big Fish Games.

On the client side, the average total CPU usage is always below 25% (Figure 11(a)). The usage is a bit higher for the wired client (Client1), since the data transfer rate is higher (See Figure 13(a)). Available free memory is  $\sim 85\%$  for both clients (Figure 12(a)).



Fig. 13. (a) Bandwidth usage, (b) Average server-client RTT PING.

Average RAM on the client side used by the Client process is ~50MB (Figure 12(b)). However, the average CPU usage is higher for Client1, i.e., 38% per one CPU. This is due to higher bitrate received by Client1, see Figure 11(b). All these figures show that both client PCs are not loaded are loaded within an acceptable CPU and memory usage range when executing the GaL software.

Average bandwidth usage for the two clients differs significantly. For Client1 (wired), it is about 14.7 Mbits/s, while for Client2 (wireless), it is 7.4Mbits/s. (See Figure 13(a).) Since both the client PCs have identical specifications, this difference is caused by the type of network connection and, more specifically, by the Transport Control Protocol (TCP) behavior over WiFi [Jurgelionis et al. 2010; Kemerlis et al. 2006]. The downlink bandwidth (3D command stream and game audio) constitutes a major part, while, as expected, the uplink bandwidth (control commands stream) represents for both clients a minor part of the total used bandwidth [Jurgelionis et al. 2009].

Average measured Round-Trip Time (RTT) for Client1 is below 1ms, while it averages 4-5ms for Client2. These RTT values do not affect the gaming experience, because even the maximum measured RTT for Client2 is under 20ms, which is below the threshold for the GaL system [Korobkin et al. 2009]. Moreover, a major part of the measured RTT could be constituted by RTT between the GaL server and the AP. The average RTT of 2-3ms could be caused by the AP or Ethernet switch and the way they treat PING packets. It should be noted that PINGs (used for RTT measurement) use ICMP (Internet Control Message Protocol) packets and many routers/switches/APs give them a lower priority. GaL 3D streaming uses TCP—and video streaming uses UDP—which routers/switches are likely to give a higher priority. Moreover, if the router supports WMM, then the GaL traffic will have the highest priority.

### 6.3. QoS Quantitative Test Evaluation

QoS quantitative tests revealed that, with regard to player experience, CPU and RAM usage values are very similar to the ones obtained in the previous study.

The bandwidth usage and RTT (Figure 14(a) and (b)) slightly differ in magnitude from those obtained in the previous quantitative tests. However, the same trends attributed to the quantitative tests are obvious. There is no effect of the additional traffic on the GaL system performance due to QoS prioritization of the GaL traffic. The maximum reached downlink bandwidth for the Internet connection during the tests was around 2Mbit/s. Bandwidth usage for Notebook 1 (NB1) and Notebook 2 (NB2) is presented in Figure 14(a). This is not a huge amount of additional traffic, even for a WLAN. Nevertheless, it is a typical traffic for this kind of Internet cafés where up to four concurrent users could be present, of which some could be using the Internet and other ones the GaL system.



Fig. 14. QoS quantitative tests, (a) Bandwidth usage, (b) Average server-client RTT PING.

## 7. DISCUSSION

New insights were gathered from the Beta evaluations at the Mentelocale Internet café. Results showed that visitors prefer playing in private settings. Digital game play in the private setting was significantly more immersive, induced higher flow, and was significantly less boring than in the public setting. In addition, digital game play in the private setting was more enjoyable than in the public setting. In practice, these results suggest that to maximise the player experience of Internet café visitors, private places should be provided, at least for single-player games. These findings seem to be in contrast with studies by Gajadhar et al. [2009, 2008a, 2009a, 2008b]. However, in our studies players were not coplayers but played their games independently. Perhaps the other person is only then seen as not meaningful and thus a distraction, which may have caused the decrease in game involvement (immersion, flow and engagement); see also [Gajadhar 2009a]. After all, experimenters did not exclusively observe more social interactions between players in a public than in the private setting. Therefore, our findings do not violate previous studies [Gajadhar et al. 2009, 2008a, 2009a, 2008b]; hence, they may even strengthen them.

Concerning the transmission of game data from the server to the end-device, a wireless stream offers multiple advantages, in particular for the mobility of the Enhanced Handheld Devices (EHD) and the constraints of a fixed network infrastructure at certain end-user sites—e.g., lack of LAN connections and cables at Internet cafés; the rooms in senior housing complexes are not always connected to a LAN network, etc. No significant differences were found on any of the player experience components between wired and wireless data streams. Moreover, no differences were found on playability and perceived control. The results imply that a single, 3D stream of a casual game to a PC end-device can be either wired or wireless, without any impact on player's experience. However, it is important to consider that the actual GaL application delay is mainly conditioned by the average frame packet size and used transmission network, and in turn, the TCP behaviour over that network. Larger frame packet sizes-the size varies for different games—when streaming over a congested wireless network (e.g., 802.11g) cause higher delays and lower frame rates, thus deteriorating the player experience [Jurgelionis et al. 2010]. In the case of 3D streaming the quality of gaming experience is typically correlated with the game frame rate or Frames per Second (FPS), which in the GaL system is proportional to the required network bandwidth [Jurgelionis et al. 2009a]. Similar correlation can be observed between the FPS, CPU, and memory utilization on the client and server [Jurgelionis et al. 2009], see also Figure 11(b) and Figure 14(a). Video games that use high datarates per frame require very high bandwidth and thus, are problematic to be deployed via current networks. This barrier is critical, since we have tested videogame titles that require 80MBit/s for running at two frames per second. But several titles require a bandwidth of up to 6-10MBit/s for running at over 20 frames per second, which is already manageable with current networks [Jurgelionis et al. 2009a]. This also suggests that it is worthwhile using a wired connection when possible, because it can offer a much higher throughput for games with higher bandwidth requirements and for multiple game streams.

Compared to the Benchmark (from the FUGA project [FUGA 2011]), the player experience with the PC end-device at the Internet café was significantly more immersive and induced higher flow. In addition, it was significantly less boring than the Benchmark. No significant differences were found on positive affect and frustration, indicating that casual game play on the PC at the café was as enjoyable as casual game play on competitive game systems that are available on the market.

Comparison of system performance data versus the player experience results, also studied in previous publications [Jurgelionis et al. 2010], provides insights into possible technical issues and their solution, and not only during the development stage, but also for system deployment. In this particular study, the measurements showed that a single GaL server could serve up to four clients simultaneously, without compromising the CPU and RAM load. From the results, it appeared that wireless networks exhibit reduced bitrates for 3D game streams which, in turn, result in a lower or even unacceptable player experience. This is because the minimum acceptable score for player's experience is and above, and, in Figure 13, we see that the bitrate for a wireless game stream is twice as small as for a wired one. This is not an issue for one game stream on WLAN, even in case of cross-traffic on the wireless network; but the bitrate could drop and thus considerably decrease the player's experience in case of multiple game streams with very high bandwidth requirements that overload the WLAN. Thus, for larger system deployments over a wireless network, it is advisable to use multiple access points to split the load of game streams across different WLANs, and multiple LPS servers should be used for load distribution. In general, a game with the highest bandwidth and CPU requirements should be used to calculate the GaL network capacity. A good rule of thumb for the WLAN deployment of a setup with similar specifications to the one described in this article and games requiring up to 6MBit/s and  ${\sim}25\%$  of CPU time would be up to four concurrent games streams per single server and per single access point.

## 8. DISCUSSION

Pervasive deployment of games in public places is an opportunity which is gathering an ever-growing interest. The GaL project has developed a system that relies on the capture of 3D graphic commands and their transmission to end-devices of various types. GaL fully supports legacy applications, thus not requiring any change for existing commercial games. The major outcome of the experiment is that the developed pervasive system is able to compete, from the point of view of the player experience, with traditional gaming systems (e.g., a program running on a single PC).

In our deployment analysis we have also seen that availability of private settings in a public place like an Internet café is key in order to maximize the overall game experience. A single-game data stream can either be wired or wireless, since the way of transmission has no effect on the player's experience. System performance measurements done in the experiments have enabled an understanding of the connection between the technical system and player-experience components and provided relevant recommendations for system deployment. Larger deployments should limit the number of concurrent game processes on the GaL server based on the deployed game with the highest CPU and network bandwidth requirements. Deployments with multiple GaL servers and/or concurrent game sessions should use wired connections when possible or be split across multiple wireless access points.

The methodology used for the tests presented in this paper can be applied to similar game streaming applications. Moreover, the results of the performed tests can be used as input for theories on social digital-game play, since the acceptable behavior in the social context seemed to have an impact on how social play is experienced.

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