Proceedings of EuroHaptics 2004, Munich Germany, June 5-7, 2004.

Experimental Study of Haptic Interaction in Distributed Virtual Environments

Rima Tfaily Souayed[1], Dominique Gaiti[1], Wai Yu [2], Gordon Dodds [3], and Alan Marshall [3]

[1] Université de Technologies de Troyes, Laboratoire ISTIT, 12 Rue Marie Curie, BP 2060, 10000 Troyes, France
{Rima.Tfaily,dominique.gaiti}@utt.fr
[2] Virtual Engineering Centre, Queen's University of Belfast, Cloreen park, Malone Road, Belfast BT9 5HN, UK
W.Yu@ qub.ac.uk
[3] School of E. &E. Engineering, Queen's University of Belfast, Ashby Bld., Stranmillis Road, Belfast, BT9 5AH, UK
{G.Dodds,A.Marshall}@ee.qub.ac.uk

Abstract. This paper reports an on-going work in which technologies are being developed to support multisensory communication for distributed virtual environments. A series of experiments for investigating the requirements of distant haptic interaction on IP-based networks have been conducted by using the custom-built experimental platforms. Existing research has identified the challenges of using haptics in distributed virtual environments and proposed several approaches to overcome these problems. However, there is still a need to investigate the network issues systematically in order to determine the allowable latency, jitter and packet loss for haptic data communication. This is one of our research objectives. In this paper, we present the details of the experimental studies that have been conducted so far.

1 Introduction

Problems arise when haptic devices are used in distributed virtual environment (DVE). For example, delay may cause a time lag between the user action and the force feedback that can result in system instability [1]. Satisfactory interaction and stable control are difficult to achieve due to the high requirements of haptic on the network which are in terms of packet loss, delay, jitter and bandwidth [2]. These requirements are stricter than other types of data. For example, to maintain stable control of a force feedback device, such as the SensAble PHANToM, an update rate of at least 1 KHz is required, whereas a reasonable video display only requires 20-30 frames per second.

In order to establish satisfactory haptic interaction in DVEs, it is important to determine their requirements in terms of network resources as well as to measure the impact of other traffic when they co-exist in the same network. Moreover, these requirements should also be assessed by the users who will determine whether the quality of service is acceptable. Both objective and subjective assessments have been carried out to determine the network parameters which give acceptable performance to the end users.

2 Platform layout

In order to study the network effects on the performance of the Distributed Haptic Virtual Environments (DHVE), two experimental platforms have been implemented.

2.1 Platform1

The first platform consists of two sites (campus buildings separated by a few hundred meters) that are linked by Gigabit Ethernet connection. One site is in the Virtual Engineering Centre (VEC) and the other site is in the Department of Electrical and Electronics Engineering (DEEE). The network topology is shown in Figure 1. The current configuration of the experimental platform consists of four 100 Mbps Ethernet segments, two 1000Mbps segments and four PCs: A, B, C and E. Computer C is connected to a PHANToM Desktop. In the experiment setup, Computer A runs the remote virtual environment whereas computers B and E are used to generate background traffic. A and B are connected to switch 1, via a 100 Mbps Fast Ethernet link while C and E are connected to switch 2 also via a 100Mbps link. Segments 3 and 4 connect the switches to the router, with 1000Mbps fiber optic links.

To capture and measure the network traffic, each computer runs a traffic generation/network analysis tool, called “IP Traffic- Test & Measure” [3]. The traffic of a DHVE runs over the link between A and C while B and/or E are used to load the network with background traffic according to the scenario being adopted.

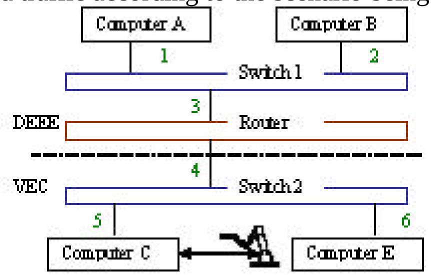

Fig. 1. Platform 1: Network Topology

2.2 Platform 2

The second platform is used to find out the upper thresholds of the QoS requirements that the DHVE requests in order to be deployed in IP networks. The effects of network delay jitter and packet loss on the interaction in DHVE is examined by using this platform. Previously, we conducted a preliminary study to determine these requirements using platform 1 [4]. However, manipulating delay, jitter and packet loss for the experiment was not possible. What we need is to emulate network impairments to determine exactly the QoS requirements of DHVE, hence platform 2 is developed.

Platform 2 consists of two co-located network subnets and three computers. The configuration of platform 2 is composed of four 100Mbps Ethernet segments and three PCs: A, B and C (Figure 2). Computer C is connected to a PHANToM Desktop. In the experiment setup, Computer A runs the remote virtual environment whereas computer B, which has two network interface cards (NIC), is used to emulate network impairments.

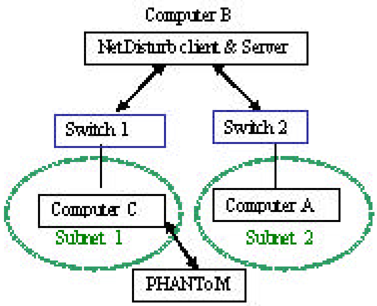

Fig. 2. Platform 2: Network impairments emulation

To study the impact of network impairment on the quality of force feedback, a network emulator has been used to simulate the different values of delay, jitter and packet loss that exist in real networks. The network emulator software, called NetDisturb from ZTI Company, consists of a client and a server part that both run on the same computer B. Different network impairments have been tested and results are collected based on a subjective assessment as explained below in the experiment design section.

3 DHVE application

The network setup provides platforms to conduct experiments on DHVE. Various types of DHVE applications can be developed and tested on these platforms. A DHVE application is developed to simulate a remote access scenario in which the user interacts with a remote virtual environment by using the PHANToM. The virtual environment runs on Computer A, and the user has access to the virtual environment through the PHANToM on Computer C. There is no local copy of the virtual environment on C, which only manages the control servo-loop of the PHANToM. In the experiments, no time delay compensation techniques have been deployed in this application. Therefore, the effect of network on the real-time control of the remote haptic interaction can be measured.

In both platforms, a peer-to-peer architecture is used to establish the network connection. The PHANToM is used to interact with a virtual object on the remote computer, and UDP (User Datagram Protocol) is used for each connection. The PHANToM's positional information is sent over the network and processed on the remote computer. Collision detection is performed in order to determine whether the PHANToM position is in contact with the virtual object. If this is the case, the position of the PHANToM is updated and prevented from penetrating the object surface before being sent back. If there is no collision, the original position is sent back to the PHANToM. Therefore, the user is able to detect the virtual object and touch its surface.

4 Experiment design

4.1 Platform 1

A number of experiments were designed to test the performance of the DHVE application under different network conditions. In the experiments, the DHVE application was run with another program called Virtual Network Computing (VNC), which displays the screen of the remote computer. By using the VNC program, the screen image of the remote computer is continuously compressed and transmitted over the network. Once received on the local computer, the image is decompressed and displayed.

In the following experiments, the DHVE and VNC programs were run for around 10 minutes and their data exchanged between Computers A and C. VNC and Haptic flows are queued in separate queues with haptic flows given premium service (the highest priority) while the VNC flow is given platinum service (lower priority) and the constant background flow is given best effort service (the lowest priority). A Priority Queuing (PQ) management mechanism is implemented to serve premium flows while a Weighted Round Robin (WRR) mechanism is implemented to serve the other queues. Flows were not metered nor shaped in the experiments. The throughput of the constant background traffic generated during experiments ranges from 0% to 90 % of segment 3's bandwidth (Figure 1). Data flows were captured, replayed, and statistics collected to calculate the packet loss, delay, jitter and throughputs of haptic flows.

Two different scenarios were conducted in the experiments:

- Scenario 1: Simulates the case of a client receiving, in addition to haptic data, a huge amount of other data, as in distributed multimedia simulations. In this scenario, computer B generates constant background traffic to computer C (Figure 1).
- Scenario 2: Simulates network congestion on segment 3 (Figure 1). In this scenario, computer B generates constant background traffic to computer E.

4.2 Platform 2

Two subjects participated in the experiment in each simulated network-impairment. Subjects are postgraduate students of the Queen's university of Belfast. The first subject was familiar with the force feedback provided by PHANToM whereas the second one was a novice. Before the experiment, both subjects were allowed to navigate in the remote virtual environment for 5 minutes without any network impairment so that they could get familiar with the feeling of networked force feedback.

Various delay, jitter and packet loss were introduced in the experiment. Before the experiments, each subject was informed about the possibility of abnormal sense of touch due to simulated network impairments. During the experiment subjects were not informed about the different values of simulated network impairments. They were asked to give a rate ranges from 7 (the best) to 1 (the worst) to indicate the sense of force feedback for each experiment. Experiments' durations differ from a couple of seconds to 5 minutes according to the type and value of simulated network impairment. Simulating different values of the same type of network impairments was randomised. Simulated values range from 0 ms to 50 ms for delay, from 1ms to 15 ms for jitter and from 0.1 % to 50 % for packet loss.

In order to enable each subject to evaluate the sense of touch precisely, they were asked firstly to find out the worst sense of force feedback which is rated as 1. The best sense of force feedback which is rated as 7 corresponds to the non-existence of network delay.

5 Experiment results

5.1 Platform 1

Scenario 1. Results in scenario 1 show that allocating haptic data the premium service as well as placing it in a separate queue guarantees very low packet loss rate. This remained close to zero up to 80% of constant background traffic. The packet loss rate reached 4.2689*10-2 at 90% of constant background traffic. These packet losses are observed only for the haptic feedback flow (i.e. there was no packet loss observed for the PHANToM flow). The Average delay was less than 1 ms except at 90% background traffic. The jitter was also acceptable at less than 2ms for both PHANToM and feedback flows. Ideally, the socket rate should be close to 1 KHz and the haptic throughput rates should be constant while haptic programs are running. We observed that the socket rate, consequently the throughput is decreasing as the amount of background traffic sent to the client increases.

Scenario 2. The results in scenario 2 showed that the packet loss was zero, delay was less than 1 ms and jitter was less than 2 ms. The sense of touch was excellent despite the fact that the socket rate was variable. This set of experiments confirms that the client machine to which a PHANToM is connected should support multiprocessors, with one dedicated processor for handling haptic threads.

5.2 Platform 2

The two subjects' evaluations were very close and sometimes the same. They used precise rate evaluation whenever only little difference is felt between two trials. Their evaluation focused on the smoothness and the stiffness of the object surface they are remotely touching and the abrupt force feedback. Results showed that as the delay between user action and the corresponding force feedback increased from 0 ms to 10 ms, the smoothness degradation of the sense of touch was very little. Results showed also that trials during which delay ranged between 11 ms and 15 ms, a light vibration was felt and the smoothness continued to degrade (figure 3). At 30 ms, smoothness was rated as 1. Beyond that value, the simulation only lasted a few seconds. There was a high risk of damage the PHANToM because of the severe vibration and the large abrupt force feedback.

Results of experiments with simulated jitter were much worse than those with constant delay. We were only able to run experiments with jitter up to 2 ms. Even at these low values, users felt small abrupt force feedback but smoothness was good (Table 1). Beyond 2 ms, experiments were stopped due to the large force error message generated by the PHANToM.

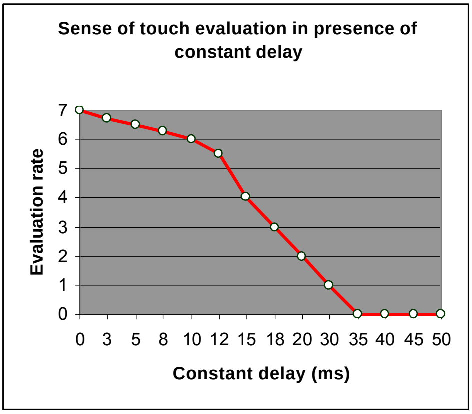

Fig. 3. Sense of touch evaluation in presence of constant network delay

Table 1. Evaluation of force feedback in presence of jitter and Packet loss

Jitter (ms)	Evaluation		Packet loss %	Condition	Evaluation
1	acceptable		0.1		Acceptable
2	acceptable		1	Non consecutive loss	Acceptable
>=3	unfeasible		5	Consecutive loss	unacceptable
			>10		unacceptable

For experiments that simulated packet loss, we should differentiate between consecutive and non consecutive packet loss. Users didn't notice any difference when packet loss rate ranges from 0 up to 0.1%. For a rate of 5 % as packet loss, smoothness degradation was little (Table 1). However, in case of 5 consecutive lost packets, smoothness, for instant, degrades considerably. In the latter case, users felt as if there were a small hole in the virtual wall.

6 Discussion

The results show that the haptic data should be given premium service and should be placed in a separate queue. Moreover, a minimum amount of bandwidth should be allocated for the haptic data. The haptic QoS requirements are summarized by less than 10 ms delay, less than 3 ms jitter, very low packet loss and sufficient allocated bandwidth according to the haptic application. In addition to haptic data's requirements in term of packet loss, delay, jitter, and bandwidth, the haptic data transmission rate should be close to 1 kHz. Implementing quality of service on network devices and applying the appropriate policies reduces the problem of network delay.

Another observation is that due to the high updating rate of the haptic device we are using, the computer's resources (to which the haptic device is connected) are taken by digitising data, formatting it into packets, transmitting it, etc. So it is recommended that the haptic and socket threads should each run on a dedicated processor. We should note that the performance of DHVEs depend on computers' specifications, available resources on computers, haptic program complexity, transmission rate, network resources, etc.

Tests on platform 2 allowed us to accurately determine the QoS requirements of haptic communication without using any compensation techniques. These requirements are 10ms for the delay between a user action and the corresponding feedback, 1 to 5% for packet loss rate, and less than 3ms for jitter. Exceeding these values the level of performance degrades considerably.

7 References

1. Motsumoto , S. et al. 2000. "The Influence of Network Issues on Haptic Collaboration in Shared Virtual Environments". Proc.of the fifth PHANToM Users Group Workshop, Aspen Colorado, October 2000.
2. Orvalho, Joao et al. 2001. "State Transmission Mechanisms for a Collaborative Virtual Environment Middleware Platform". In Proc. of IDMS'2001 - 8th International Workshop on Interactive Distributed Multimedia Systems, Lancaster, United Kingdom, September, 2001.
3. ZTI Company. "IP Traffic-Test & Measure". http://www.zti-telecom.com
4. Tfaily Souayed R. et al. 2003. "Haptic Virtual Environment Performance Over IP Networks: A Case Study", In Proc. of the IEEE DS-RT03 , pages 181-189, Delft, The Netherlands, October 2003.