Real Time Haptic Data Transferring

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***Abstract*—The improvement of the Internet's network conditions have made possible for the real time Haptic data transferring over the Internet. With the word Haptic we refer to the sense of touch that the user feels when he uses a Haptic service. This paper deals with the transfer of real time Haptic data over the Internet. It presents the related work on Haptic data transferring. It outlines the Haptic data transmission characteristics and the necessary QoS requirements for the maximization of the Quality of Experience for Haptic users. It describes a proposed Haptic system architecture. It analyses the metrics that have to be taken into consideration for the evaluation of Haptic transferring. It also presents experiments for real time Haptic data transferring that have been carried out by the authors through different networks and locations.**

Keywords—Haptics, interactive applications, Internet status, real time transport protocols

I. Introduction

Last decade improvements on the Internet network conditions have made it possible to transfer real-time teleoperation commands of robot systems through the Internet. The feedback that the user perceives from such a teleoperation can be either a tactile or a kinesthetic feedback. Both of them are known as Haptic feedback.

In order to fulfill the necessary QoS for Haptic data transferring over the Internet the transport protocol should support some qualitative features such as Prioritization, Reliability, Flow/congestion control, Minimum Overhead, Buffer Optimization, differential coding, quantization, packetization and Synchronization [1].

The rest of the paper is organized as follows. Section II presents the related work on Haptic data transferring. Section III describes a high level Haptic system architecture. Section IV outlines the QoS requirements for Haptic data transferring. Section V presents experiments for Haptic data transferring. Finally section VI identifies conclusions and future work.

II. RELATED WORK ON HAPTIC DATA TRANSFERRING

Several studies [2] have shown that Haptic applications are sensitive to network conditions such as network delay, jitter and packet loss. Such network conditions are often encountered over the Internet. Many interesting techniques have been proposed to mitigate the delay and the jitter of the network [1]. Most of these techniques are based on the reduction of the sending rate of the Haptic packets, the increase of the prioritization of the most significant packets, and the reduction of the size of the Haptic packet via compression techniques.

One interesting technique that tries to lower the sending rate of the Haptic packet is the dead-reckoning theory [3]. It is based on the Weber's Law of Just Noticeable Difference (JND) [3] and it is expressed through the equation (1). The parameter I express the stimulus that the user feels when he uses a Haptic interface and the factor κ is a constant that is called weber fraction. The dead-reckoning theory supports that, packets that produces difference in the user's stimulus intense smaller than the ΔI, should obtain lower transmission priority or even dropped.

$$\Delta I = I * \kappa \tag{1}$$

One more interesting data rate reduction technique is the prediction-based packet reduction [4]. This technique supports that if packets can be satisfactorily predicted at the receiver side from previously sent packets then those packets could be omitted.

Another data rate reduction technique is the event based prioritization [5]. Haptic packets that describe events with great significance should obtain higher priority than Haptic packets that describe lower significance events. When network conditions are not adequate packets with lower priority should be dropped.

The traditional transport protocols of the internet such as the TCP and the UDP cannot fulfill the QoS requirements for Haptic data transferring over the Internet [6]. The protocols that have been proposed for the Haptic data transmission are the SMOOTHED-SCTP [7], the IRTP [8], the ALPHAN [9], the ETP [10], and RTP/I [11]. All the above protocols use the UDP protocol as the main transmission protocol with some additional features in order to increase their reliability, enforce congestion control and minimize the jitter effect [12].

III. A PROPOSED HAPTIC SYSTEM ARCHITECTURE

The system architecture that the authors propose is depicted in Figure I. It is obvious that there are three different channels.

The first channel is the Haptic control channel. It carries commands from the user to the remote Haptic equipment. Strict QoS requirements should be enforced to that channel as Haptics are very sensitive to network delay and jitter.

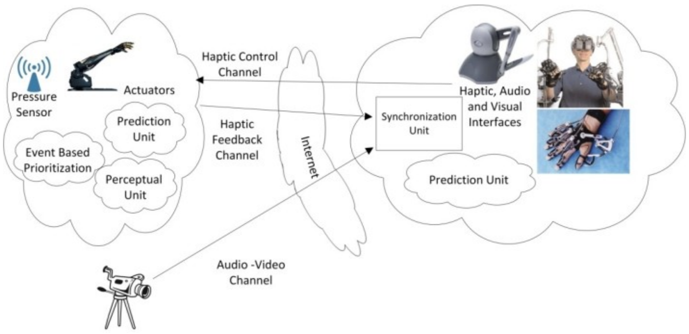

Fig. 1. High level architectural design of the Proposed Haptic System.

The second channel is the Haptic feedback channel. It carries responses from the remote Haptic equipment to the Haptic interface user. Again strict QoS requirements should be enforced as network delay and jitter are very crucial for this channel. Lower jitter and delay corresponds to higher Quality of Experience (QoE) for user.

The third channel is the audio-video channel. This channel absorbs the greater bandwidth as video is very demanding to network bandwidth.

Multiplexing techniques could be enforced at the Haptic Feedback channel and the Audio-video channel in order to maximize synchronization and lower the necessary bandwidth.

The synchronization unit is necessary for the synchronization of all the above streams [13] in order to maximize the Quality of Experience of the user.

The Prediction Unit, the Perceptual Unit and the Event Based Prioritization Unit are enforcing the data rate reduction techniques of the previous section.

IV. QoS REQUIREMENTS FOR HAPTIC DATA TRANSFERRING

Lot of research [2] has been conducted in order to infer the Quality of Service requirements for Haptic data transferring. The results of this research are depicted in Table I.

TABLE I. QoS REQUIREMENTS FOR SUPERMEDIA APPLICATIONS [2]

QOS	*HAPTICS*	*VIDEO*	*AUDIO*	*GRAPHICS*
JITTER (ms)	≤ 2	≤ 30	≤ 30	≤ 30
DELAY (ms)	≤ 50	≤ 400	≤ 150	≤ 100-300
PACKET LOSS (%)	≤ 10	≤ 1	≤ 1	≤ 10
UPDATE RATE (Hz)	≥ 1000	≥ 30	≥ 50	≥ 30
PACKET SIZE (bytes)	64-128	≤ MTU	160-320	192-5000
THROUGHPUT (kbps)	512-1024	2500-40000	64-128	45-1200

In order to meet the strict requirements of Table I, specialized for Haptics, transport protocols should be used. As Haptics require timely delivery of information with so big update frequencies (1 kHz) with so little delay (<50 ms) and jitter (<10 ms) common transport protocols could not be used. Some protocols that have already been proposed for Haptic transferring are the SMOOTHED-SCTP, the IRTP, the ALPHAN, the ETP, and RTP/I.

V. EXPERIMENTS FOR REAL TIME HAPTIC DATA TRANSFERRING

A. *Experiments over wired network connections*

The Haptic applications are very sensitive to network conditions. In order to detect the network conditions of the Internet, experiments are undertaken between two different cities in Greece and within two different network connections. The cities that are chosen are the city of Grevena and Thessaloniki. The networks that have been used are a simple 24 Mbps Downlink/ 1Mbps uplink ADSLv2 line and the Greek Academic network GRNET that connects local universities and research institutions via dark fiber at speeds up to 10Gbps.

The authors have actively measured the average end-to-end delay, the standard delay variation, also called jitter, the packet loss and the number of hops between these destinations. They sent 3000 ICMP packet every 3 hours for 24 hours. The results of these measurements are presented in Table II.

TABLE II. NETWORK STATUS FOR COMMMUNICATION BETWEEN CITIES

NETWORK STATUS	*DELAY (ms)*	*JITTER (ms)*	*PACKET LOSS (%)*	*HOPS*
GREVENA – THESSALONIKH THROUGH GRNET	*19.12*	*1.70*	*0*	*5*
GREVENA – THESSALONIKH THROUGH ADSLv2 LINE	*53.19*	*5.31*	*0.11*	*8*

It is understood that when the two destinations are connected through the GRNET network all the results satisfy the QoS requirements of Table I. On the other hand, when the two destinations are connected through the ADSL line then the measured delay and the jitter are a little higher than the corresponding thresholds of the Table I. From this comparison, it is understood that the QoS that the Internet Service provider enforces on the network is crucial for the successful transfer of the Haptic data.

Another experiment that the authors have already made is the active measurement of the network status between three intercontinental destinations. The three destinations that were chosen were Greece, Japan and Korea [14]. Again the authors sent 3000 ICMP packets every 3 hours for 24 hours. The measured metrics were again the delay, the jitter, the packet loss and the number of hops between the destinations. The results of these measurements are depicted in Table III.

TABLE III. INTERNET STATUS FOR INTERCONTINENTAL COMMUNICATION [14]

INTERNET STATUS	*AVG. DELAY (ms)*	*JITTER (ms)*	*PACKET LOSS (%)*	*HOPS*

JAPAN - KOREA	27.01	0.19	0.02	11
JAPAN - GREECE	331.10	6.30	1.53	26

It is understood that the network status between Japan and Korea satisfy the all the thresholds of Table I. On the other hand the network status between Japan and Greece were rather disappointing. The average delay was rather high, while the jitter was a little higher than the threshold of Table I.

B. Experiments over wireless network connections

In order to evaluate the 802.11g wireless communication standard protocol for Haptic data transferring the authors sent streams of data with different packet rate and packet size. Two packet rate were used, 1000 and 500 packets per second. The packet size was 64, 128 and 256 bytes. Two different wireless topologies were used. The first topology was a simple WiFi network with no Access Point (AP) repeaters. The second topology was a WiFi network with one wireless AP repeater. The AP that was used was the 300 Mbps Tenda A30 Wireless N300 Range Extender. The metrics that were used were the Round Trip Time (RTT), the standard deviation of the RTT and the Packet Loss. The application was implemented with visual C++ socket programming. The transport protocol that was used was the UDP protocol. The results from the above protocols are depicted in Table IV.

TABLE IV. NETWORK STATUS FOR SUPERMEDIA STREAMS

Network	*Packet Rate (Packets /sec)*	*Packet Size (Bytes)*	*Round Trip Time (ms)*	*Standard Variation of RTT (ms)*	*Packet Loss (%)*
WiFi with no AP Repeaters	1000	64	3.65	6.19	0.06
WiFi with no AP Repeaters	1000	128	3.8	6.59	0
WiFi with no AP Repeaters	500	128	3.21	5.15	0
WiFi with no AP Repeaters	500	256	3.78	6.18	0.07
WiFi with 1 AP Repeater	1000	64	11.18	8.85	0.39
WiFi with 1 AP Repeater	1000	128	14.97	17.98	0.8
WiFi with 1 AP Repeater	500	128	7.37	8.20	0.4
WiFi with 1 AP Repeater	500	256	10.98	15.16	0.42

Table IV depicts that the RTT and the packet loss for all networks, packet rate and packet size combinations is by far smaller than the threshold of the delay of Table I. On the other hand the standard deviation of the RTT is a little bit bigger than the threshold of jitter in Table I. Moreover, Table IV shows that WiFi networks with wireless AP repeaters have greater RTT and jitter than simple WiFi networks. Furthermore, it is obvious that when the packet size increases the RTT and jitter increases as well. Moreover, when the packet size increases, the RTT and jitter is also increased. The most interesting conclusion of Table IV is that, if we want to lower the delay and the jitter of the network, while keeping the throughput steady, which is the multiplication of the packet rate with the packet size, we should increase the packet size and lower respectively the packet rate. This conclusion can be very useful in congestion control algorithms.

VI. CONCLUSIONS AND FUTURE WORK

Based on the experiments of section 5, is determined that the transfer of the Haptic feeling through the Internet is feasible with limitations due to the geographical distance and network conditions. It puzzles out the role of the Internet Service Providers and the QoS that have to enforce in their networks in order the user's Quality of Experience to be maximized. The role of the distance and the number of hops between the source and the destination is clarified. It is also obvious that the transfer of Haptic data through WiFi networks is feasible.

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