Providing QoS for Multimodal System Traffic Flows in Distributed Haptic Virtual Environments

Kian Meng Yap, Alan Marshall, Wai Yu
Virtual Engineering Centre
School of Electronics, Electrical Engineering & Computer Science
Queen's University Belfast
Belfast BT9 5HN, Northern Ireland, U.K.
Phone: - +44 28 9097 5588 Fax:- +44 28 9097 4332
{m.yap, a.marshall, w.yu}@qub.ac.uk.

***Abstract*—Future internet architectures will be required to support the transmission of data that is multimodal in nature, and this will include the ability to transport reflected force, or haptic information. This paper presents for the first time, an investigation into providing specific network Quality of Service (QoS) for haptic traffic together with voice and video traffic. Because it originates from a different human sense, the QoS required to support haptic traffic is significantly different from that used to support conventional real-time traffic such as voice or video. Each type of network impairment has different (and severe) impacts on the user's haptic experience. While some recent efforts have established the basic range of the network QoS parameters for haptic interaction, to date there has been no specific provision for this traffic over a QoS enabled IP network. The work presented here involves both simulation and practical experimentation whereby haptics, voice and video are transmitted over a best effort IP network and a QoS-enabled IP network. The results show that the network simulation model compares favourably with the physical network, and can be used to generate a scalable haptic network model where multiple connections carrying haptic traffic may be examined. Both approaches show that reducing network delay and jitter by using specific QoS classes for haptic traffic can lead to improvements in users' haptic experiences with distributed applications such as virtual environments.**

***Index Terms*—Haptic, distributed virtual environment, network simulation, multimodal traffic, QoS.**

I. Introduction

The future Internet will have to carry a wide range of applications, and many of these will incorporate new types of traffic. There has been recent interest in the transmission of multimodal information over the internet [1], and in particular the transmission of haptic[1] information [2][3]. Haptic sensing is the kinaesthesia of events such as heat, pressure, force, or vibration. 3D virtual environments have been used in numerous research areas including gaming, tele-robotics, education training and interactive advertisements, as well as in hazardous industries. Tele-haptic applications concern remote haptic operations over network connections. In particular, the integration of haptics with virtual environment has opened up a new research area for network communication. Computer-haptic and human-haptic [4] interactions are changing the way humans communicate with each other and with machines. Human haptics concerns using our human sensory systems (mainly the hands) to interact with, explore and manipulate virtual environments through the stimuli of touch, motion and force. This is generally implemented by haptic devices which allow users to touch and feel the weight, shape, motion and acceleration of virtual objects. Touch and manipulation in virtual environments require computational algorithms to determine collision detection, and provide stable force feedback for haptic rendering in virtual environment. Introducing the sense of touch into virtual environments can profoundly improve the way we interact with them. Haptic Virtual Environments (HVEs) support interfaces between a haptic device and a virtual environment. HVE uses include military and space exploration; the sense of touch will also enable blind people to interact with each other within a virtual environment. The HVE modalities include graphics (and possibly video), sound and force. Recent research [2][3] has shown that to have a satisfying experience in interacting with a HVE, the graphics and haptic update rates need to be maintained at around 30Hz and 1 KHz respectively.

To date, almost all haptic applications are designed whereby the haptic device is connected to a single stand-alone system, or where dedicated connections are used to provide remote interaction. Distributed Haptic Virtual Environments (DHVEs) extend the HVE concept whereby users in different geographical locations can interact with the virtual environment or among each other, each using their own haptic

[1] Haptic is sense of touch and force feedback and comes from the Greek word "haptikos" *to grasp, touch*, and concerns the sense of touch and force feedback through the human sensory system.

devices. It is clear that the capability to distribute haptic applications across a universally accessible medium such as the Internet will dramatically increase their profile to a much wider range of users.

Typically, different types of data are exchanged between hosts in DHVE systems (e.g. graphics, audio, positional information and reflected force). The effective transmission of haptic data (force feedback) in DHVEs is a new research area which presents a number of challenges to the underlying network. It is now accepted that the best effort service offered by current IP networks is insufficient to meet the needs of these types of applications, which require specific guarantees from network. Recent studies have shown that the haptic experience deteriorates as network-induced packet delay and packet jitter increases beyond 30ms and 2ms respectively [2][3].

A major challenge is therefore to provide the QoS to improve the transmission of haptic traffic in multimodal systems such as DHVEs when they are considered for use over the Internet. The objective is therefore to reduce haptic traffic delay and jitter in distributed multi-sensory environments so that stable user experiences can be achieved while performing collaborative haptic operations under the effects of network impairments. The contributions of the work presented in this paper are: (i) a new peer-to-peer DHVE application that can be used in order to generate haptic traffic over networks, (ii) a custom OPNET Probability Density Function (PDF) model [3] has been developed in order to permit conventional network simulation software to examine large-scale haptic traffic, (iii) examination of the behaviour of haptic traffic in IP networks with and without QoS, and (iv) recommendations to improve transmission of haptic traffic using Class Based Weight Fair Queue (CBWFQ) and implementation of Diffserv Code Point (DSCP) are also presented.

II. RELATED RESEARCH IN NETWORKED HAPTICS

A number of systems have been developed specifically for haptic collaboration, including DIVE, CALVIN, and COVEN [5]. Some researchers have attempted to characteristic the network parameters required for medical applications. In [6] it is reported that a good user experience using a haptic autohandshake requires: 128kbps bandwidth, <10 percent packet loss, delay <20ms and jitter <1ms. In order to achieve a good user perception of remote stereo viewing requires: 40Mbps bandwidth, packet loss <0.01%, delay <100ms and is not sensitive to jitter. Jeffay [1] investigates the problem of supporting continuous data generated by Distributed Virtual Environment application (DVEs). The experiment described considers the effect of delay and delay-jitter on the haptic force display. Instead of presenting a solid, sharp-edged, stable surface, delayed force feedback results in soft, mushy surfaces, making the use of haptics ineffective or unstable. Experiments were conducted in a router for three types of flow control: First In First Out, (FIFO), Random Early Detection (RED) and, Class Based Threshold (CBT). The best QoS achieved used the CBT flow control with a packet drop-rate of 1.3%, average latency 28.4ms and an average TCP throughput of 790kBps.

Allison [7] considers the effects of varying amounts of simulated constant delay on the performance of a simple collaborative haptic task. The task was performed with haptic feedback alone or with visual feedback alone. Subjects were required to pull a virtual linear string as rapidly as possible, while maintaining a target simulated spring force between their end effectors and that of their collaborators. When delay increased, it resulted in a decrease in performance, either in deviation from target spring force and in increased time to complete the task. In their experiment, they incorporate the TiDeC™ [8] in order to reduce the effect of network delay.

The majority of the preceding work has not considered how to effectively transmit haptic traffic by applying QoS mechanisms. It is recognized that the performance of multimedia traffic can be improved by using QoS mechanisms that reduce network impairments [9], and it is therefore expected that the performance of DHVE-based applications can also be enhanced by applying QoS architectures such as Diffserv [10]. Our study has been conducted with both experimental and simulation models in order to study the network QoS characteristics required for haptic traffic. The work presented here further extends our previous work [3] to investigate the provision of QoS for haptic media in networks carrying multimodal traffic.

III. DISTRIBUTED HAPTIC VIRTUAL ENVIRONMENT ARCHITECTURES

In collaborative DHVEs users take turns in manipulating the virtual objects while in co-operative DHVEs they can simultaneously modify them [11]. We use a Peer-to-Peer DHVE system architecture throughout our studies. Most collaborative (or co-operative) virtual environments adopt one of two commonly available network distribution architectures: client-server or peer-to-peer. Each architecture has its own specific advantages and shortcomings. Client-server architectures provide consistency and synchronization among the clients because simulation activities are processed in a centralized server. Also, the required computing power of each client is lower than that required for peer-to-peer systems. The biggest disadvantage of the client-server approach is that the local view of the environment is only updated after a round-trip to the server, which may impart a significant delay. The client-server architecture also has a scalability problem as the number of clients increase so the load on the server can increase exponentially. Peer-to-peer systems offer the benefits of scalability and decentralized control, but there are significant challenges associated with synchronizing not only the virtual environments across networked peers, but also the transmitted forces.

A. Haptic Traffic Network Parameters

Real time transmission with low latency over long distance is the main challenge for networked haptic applications. The aim of network level QoS is to provide stable bandwidth, controlled jitter (i.e. consistent latency) in addition to improved packet loss. The QoS parameter values for haptic traffic are different from traditional real-time (e.g. VOIP) Internet applications; for example, network latency >50ms can lead to instability in tele-haptic interaction. The network characteristics considered for the DHVE flows are the bandwidth of the connection, the packet delay, packet jitter, and packet loss. Table 1 shows the DHVE haptic traffic network parameters versus other types of network service. It is clear that haptic media is more sensitive to delay and jitter than other traffic types.

TABLE 1. DHVE HAPTIC TRAFFIC VERSUS OTHER SERVICE TYPES NETWORK PARAMETERS SUMMARY [2][3][[12][13][14]

Traffic	Characteristics	QoS Requirements
Haptic	Transmission rate of 1000 packet/sec.	Delay < ~ 50ms.
	Constant packet rate.	Throughput ~ 500kbps-1Mbps
	Sensitive to jitter and delay.	Packet loss < ~ 10%
		Jitter < ~ 2ms.
Voice	Alternating talk spurts.	Delay < ~ 150ms
		Throughput ~ 22kbps-200kbps
	Silence interval.	Jitter < ~30ms
	Talk-spurts produce constant packet.	Packet loss < ~ 1%
Video	Highly bursty traffic.	Delay < ~ 400ms
	Long range dependencies.	Jitter < ~ 30ms.
		Throughput ~ 2.5Mbps-5Mbps
		Packet loss < ~ 1%
Data	Poisson type.	Zero or near-zero packet loss.
	Long range dependencies.	Delay may be important.

B. Experiment and Simulation Approaches

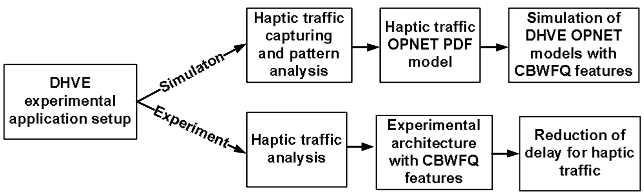

Fig. 1. Experiment and simulation approaches to obtain the results in section VI

Fig. 1 shows the approaches taken. Haptic traffic was first captured in an experimental test bed, and the subsequent, traffic patterns analyzed and a custom OPNET PDF model created [3]. A simulation model of DHVE applications running over a network was then created. The OPNET simulation network model is similar to the experiment test bed. The PDF model is used to generate haptic traffic to run in the simulated DiffServ network. Subsequently, the effect of running haptic traffic over a DiffServ IP network is obtained. This approach is used to overcome limitation of test bed. We are able to simulate a large scale DHVE simulation model without the restriction of physical resources. However, the limitation of simulation model is that we cannot simulate user's haptic perception which can only be studied in experiment environment.

IV. EXPERIMENTAL ARCHITECTURE

In Fig. 2, there are four computers involved in the experiment and connected through a bottleneck Ethernet link. The Ethernet link is running on limited bandwidth of 10Mbps through the two Cisco [15] routers A and B. We use two PHANToMs along with Matlab Simulink, and the proSENSE toolbox from HandshakeVR [8] to develop our experimental system. The force feedback device used is the PHANToM desktop [16] from SensAble Technologies Inc. This is used to manipulate moving virtual objects and to provide the user with feedback from the virtual environment. The PHANToM desktop has an arm workspace of 16cm x 12cm x 7cm and can provide force up to 3.3N in 3 axis directions; the force computation is based on the spring-damper model [16]. The PHANToM desktop has maximum stiffness of (3*103 N/m) to allow realistic simulation of contact with walls and hard objects. It can generate 1000 packets/sec of position and force data during haptic collaboration actions.

In operation, PCs 1 and 2 are running DHVE Matlab applications while PCs 3 and 4 functions as background traffic generators for the bottleneck link. The haptic traffic is given various CBWFQ weights in contrast with a constant background traffic weight. Fig. 3 shows the Matlab haptic environment which consists of a work platform, one moving cube, one static cube and two ball spheres which represent local and remote PHANToM cursors (Haptic Interface Points). The size of the virtual cubes is 4cm x 4cm x 4cm. The workspace boundary is 7cm on each side. The cubes are modeled to simulate the mass, damping, form, position, velocity and acceleration of the dynamic virtual objects. Their physical properties are: mass=5kg, stiffness=300N/m and damping factor=7 respectively. When running, users at PCs 1 and PC 2 push the virtual objects which are 3D cubes in a virtual environment. Force is generated when PHANToM is touching the virtual cube. This force data is transmitted from PC1 to PC2 and vice versa. The traffic flowing between all the computers are captured by using the IP Traffic package [17], this was found to require 736 kbps for haptic traffic in each direction. The haptic systems generate 1000 packets/sec; the data field of a haptic packet is 106 bytes. Details of the haptic

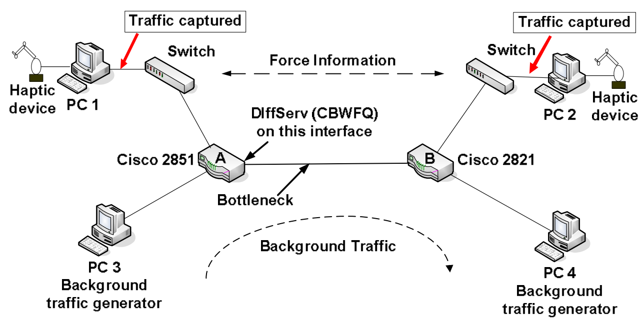

Fig. 2. Experimental model of distributed peer-to-peer architecture

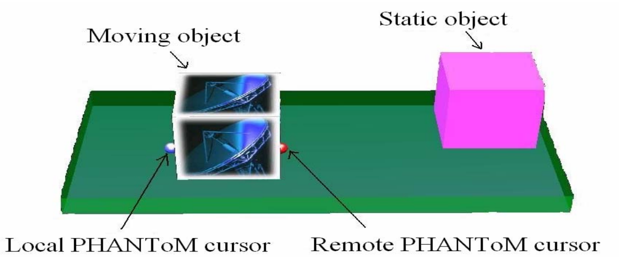

Fig. 3. Snapshot of the implemented collaborative haptic virtual environment

traffic patterns are presented in [3]. Subsequently, we have created PDF models in OPNET [13] and use the PDF model to simulate haptic traffic with multimedia traffic sources.

A. Haptic Traffic Weight Fair Queuing Configurations

Fig. 4 shows the queue setup of haptic and background traffic for the output port (egress port) of Cisco router A in the experimental test bed shown in Fig. 2. The haptic traffic class is set with Weighted Fair Queue (WFQ) weights of 0, 1, 5, 10, 15 or 30. A Similar setup is applied to the egress interface of Router A in the simulation model shown in Fig. 5. Voice and video applications are treated in different classes during WFQ classifications. The background traffic class is set to best effort. In order to improve the haptic traffic transmission under background traffic load, the CBWFQ weight of the haptic traffic class was varied. The haptic class weight was not set higher than 30 because after that the delay is almost zero. This is because the CBWFQ guarantees enough bandwidth (736 kbps in our application) for haptic traffic. Percentage background traffic is calculated with the ratio of 10Mbps. For example, a 10 percent of background traffic will generate 1Mbps from router A to router B.

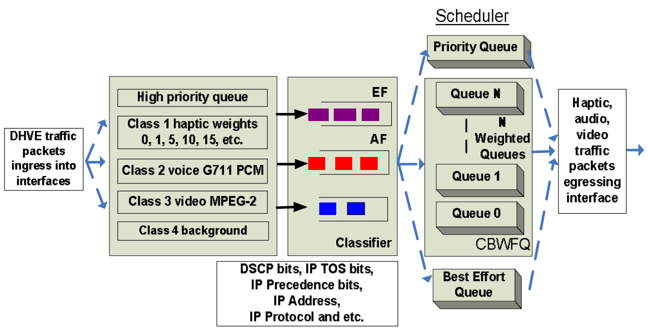

Fig. 4. Diffserv treatments for haptic, audio, video and background traffic packets

V. DHVE SIMULATION MODEL

The network simulator OPNET Modeler was used to simulate Distributed Haptic Network environment. As there is no generalized distribution model that is able to represent haptic traffic, a custom PDF model was created. Details of this model are presented in [3]. Fig. 5 shows the DHVE model in which the eighteen PCs are connected with two switches and routers. The routers A and B are connected by a bottleneck link of 10Mbps in order to study the effect of WFQ on haptic traffic. The other network links are 100Mbps. The Haptic

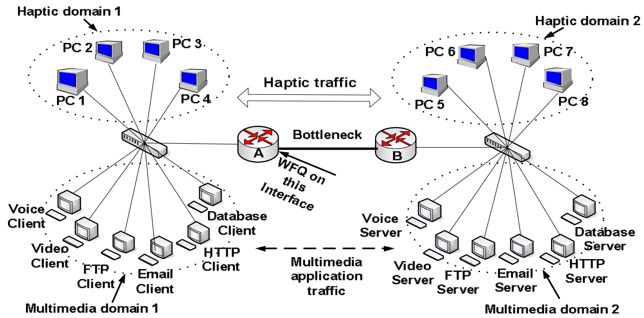

Fig. 5. Distributed haptic virtual network simulation model

Domains 1, 2 are configured to run a custom application task that simulates a DHVE application by using the custom OPNET PDF model. In addition, the PCs run MPEG-2 video, G.711 voice, FTP, Email, HTTP and Database applications. The system runs with WFQ enabled in the output interface of router A. The weight assigned to haptic traffic is then increased in steps. Additionally, a Low Latency Queue (LLQ), which is equivalent to Diffserv's EF queue, provides a priority queue function.

VI. EXPERIMENTAL AND SIMULATION RESULTS

A. Experiment Results

Fig. 6 shows the results obtained from the experimental test bed when haptic traffic is allocated CBWFQ bandwidth weights of 1, 5, 10 and 30. The result shows that when the haptic traffic is allocated higher bandwidth, the packet transit delay is reduced. In Fig. 6, haptic traffic end-to-end delay increases to 200ms whenever the background traffic increases and the haptic traffic is given Best Effort treatment. When CBWFQ is employed, the haptic traffic delay is significantly reduced. Setting the CBWFQ haptic weight=1 with a guaranteed bandwidth of 1 Mbps results in a significant improvement over best effort, and weights of 10 and 30 can definitely reduce the delay further (e.g. CBWFQ weight=30 the haptic delay is reduced to less than 1ms with 95% background load).

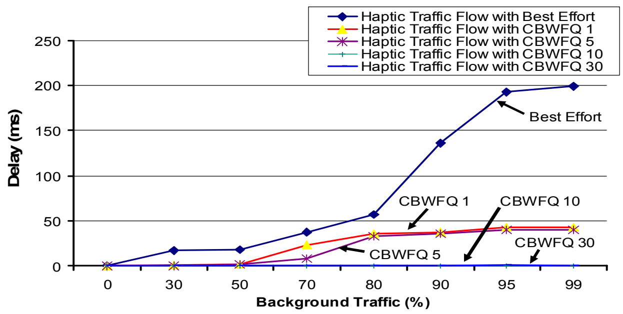

Fig. 6. Haptic traffic end-to-end delay versus background with different WFQ weights at egress interface of router A

B. Simulation Results

Fig. 7 shows end-to-end delay of individual haptic, voice and video traffic flows with 0-45% background traffic loading on the bottleneck link (10Mbps). The combined flows increase

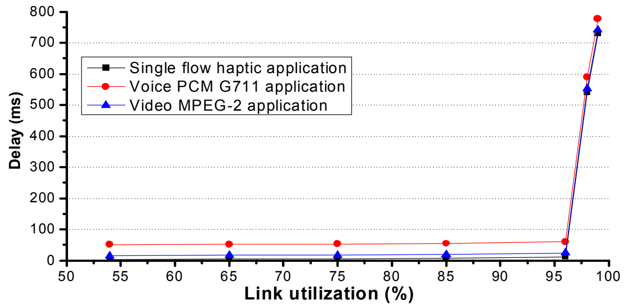

Fig. 7. Haptic, voice and video traffic end-to-end traffic delay versus bottleneck link utilization (100% = 10Mbps) (Best Effort Service)

the bottleneck link utilization up to 98%. Fig 7 shows that with a best effort only service, haptic traffic incurs nearly 730ms of end-to-end delay which is totally unacceptable for a haptic operation. The simulation results shown in Fig. 8 are the end-to-end delay of the haptic, voice and video traffic flows with different WFQ weights. The results are obtained by varying the weights for all other traffic (except haptic traffic) flowing through the output interface of router A. The audio and video traffics have been set to achieve end-to-end delays of below 100ms. The WFQ weight ranges from best effort (WFQ=0) to WFQ weight = 15. Initially, the best effort IP network caused end-to-end 800ms delay in the haptic traffic; however, this delay is improved by introducing prioritised service class for haptic traffic. It can be observed that the end-to-end delay of the haptic traffic has decreased from 800ms (WFQ weight = 2) to 1.14ms (WFQ weight = 15). The delay is further reduced to 0.7ms with the Low Latency Queue (LLQ) enabled on the interface. The result shows that the introduction of WFQ improves the QoS provided to the haptic traffic. Fig. 9 shows haptic traffic throughput at the Ethernet layer, it highlights the reduction in throughput when WFQ weight < 9.

C. *Discussion of Results*

Section VI has presented the experimental and simulation results respectively. The end-to-end delay of the simulated haptic traffic decreases to about 2ms when the WFQ weight is 9. However, the experiment result shows that the end-to-end delay drops to 40ms when CBWFQ weight=1. This is because WFQ can allocate a minimum amount of bandwidth exclusively for haptic traffic.

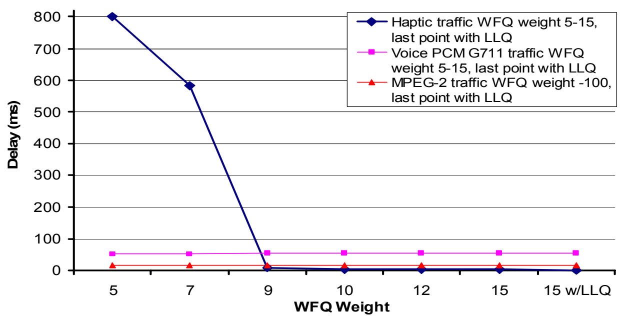

Fig. 8. End-to-end delay of haptic, voice and video traffic with different WFQ weights

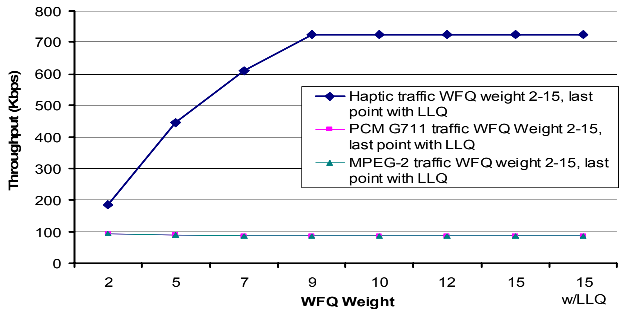

Fig. 9. Haptic, voice and video traffic throughput with different WFQ weights

The haptic traffic is therefore able to improve its transmission quality if guaranteed a minimum amount of network bandwidth. This is shown for both experiment and simulation results. From the experiment results, the user haptic perception is improved when there is CBWFQ enabled in the network. We have also studied the consequence of using DSCP for haptic traffic as shown in Table 2. The haptic traffic is studied for maximum end-to-end delay under different AF and EF of DSCP Markings. EF with Low Latency Queue (LLQ) provides highest priority thus yielding lowest delay. Table 2 shows that the AF21-AF23, AF31-AF33, AF41-AF43 and EF have lower end-to-end delays compared to AF11-AF13. Therefore, AF11-AF13 are not recommended for transmission of haptic, audio or video traffic. This is in agreement with IETF recommendations (RFC4594) for the transport of video and voice traffic [14].

TABLE 2. MAXIMUM END-TO-END DELAY OF HAPTIC, VOICE AND VIDEO TRAFFIC WITH DIFFERENT DIFFSERV CODE POINT (DSCP) AF AND EF MARKING. NOTE: BE – BEST EFFORT, AF – ASSURED FORWARD, EF – EXPEDITED FORWARD, LLQ – LOW LATENCY QUEUE, LINK T3 – 45MBPS, 95% LINK UTILISATION.

DSCP	End-to-end Delay (ms)		
	Haptic	Voice	Video
BE	1206.8306	1254.7928	1023.2244
AF11	217.8382	284.8830	235.8420
AF12	217.8382	284.8830	235.8420
AF13	217.8382	284.8830	235.8420
AF21	1.7631	49.4548	6.5655
AF22	1.7631	49.4548	6.5655
AF23	1.7631	49.4548	6.5655
AF31	1.6851	49.3732	5.8811
AF32	1.6851	49.3732	5.8811
AF33	1.6851	49.3732	5.8811
AF41	1.6382	49.3348	5.5212
AF42	1.6382	49.3348	5.5212
AF43	1.6382	49.3348	5.5212
EF	1.5952	49.2930	4.9335
EF LLQ	1.5868	49.2871	4.8084

Fig. 9 shows that the haptic traffic has an average throughput of 736kbps. Therefore, it is important to reserve this minimum bandwidth in order for the haptic traffic to be effectively transmitted. Based on our findings, we propose a DSCP marking scheme for haptic traffic. The requirement for configuring a managed network by the network administrator for transporting haptic traffic is proposed in Table 3. The haptic class is comparable to telephony or video classes but it is very sensitive to jitter [9][18] and is proposed to have a DSCP marking of EF or at least AF21 and above.

TABLE 3. PROPOSED HAPTIC CLASS WITH DSCP MARKING SCHEME IN ADDITION TO DIFFSERV SERVICE CLASSES AND DSCP MARKING SCHEME IN [14]

Service Class	Traffic Characteristics	Tolerance To			Protocol	DSCP
		Loss	Delay	Jitter		
Haptic	Fixed size packets, real-time, inelastic and constant rate flows	Very low	Very low	Extreme low	UDP	EF
Telephony	Fixed size small packets, inelastic and low rate flows	Very low	Very low	Very low	UDP	EF
Multimedia streaming	Variable size packets, elastic with variable rate	Low-medium	Medium	Yes	UDP	AF31 AF32 AF33
Low priority data	Non real-time and elastic	High	High	Yes	N/A	BE

VII. CONCLUSIONS AND FUTURE WORK

This paper presents a novel study into how to apply Diffserv WFQ techniques in transmitting haptic traffic in an IP QoS-enabled architecture. The investigation uses an experimental test bed and simulation models. The work involves comparisons of haptic, voice and video traffics in best effort and Diffserv networks in which Diffserv uses WFQ and CBWFQ as the traffic prioritisation mechanism. Both simulation and experimental results show that transmission of haptic traffic is improved by the introduction of WFQ and CBWFQ respectively. The end-to-end delay of voice and video applications in simulation model are maintained at below 100ms in order to make it a practical model to study multimodal systems. Our simulation model can be used to simulate haptic traffic in large scale packet-switched IP networks. This work leads to a conclusion that by properly configuring WFQ and CBWFQ in a DiffServ packet switched network, the performance of haptic applications i.e. the users' "haptic experience" can be significantly improved. Subsequently, a haptic traffic class with DSCP marking scheme is proposed.

In the future, we will conduct haptic user perception tests under a DiffServ IP QoS network with multiple users. In addition, we will study the application of traffic conditioning strategies such as Custom Queuing, Weighted Random Early Detection (WRED) and Interleaving, which are specifically configured to improve haptic traffic under congestion conditions.

ACKNOWLEDGMENT

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