Providing QoS for Distributed Haptic Virtual Environments in IP Networks

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ABSTRACT
In this paper, we study the transmission of haptic traffic over a best effort IP network and a DiffServ-enabled IP network. The work involves both simulation and practical experimentation. Packet switched networks such as the Internet will shortly need to support many different types of applications which will use multi-modal data including reflected force or haptic data. Recent research has established that the Quality of Service (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. This paper presents for the first time, an investigation into providing specific network quality for haptic traffic. The work considers two approaches: simulation and practical experimentation. Our results show the network simulation model compares favourably with the physical network, and can be used to generate a scalable haptic network model where multiple DHVE connections may be examined. Both approaches show that delay and throughput of haptic experience can be improved by using specific QoS class from DiffServ for haptic traffic.

Keywords
haptic, distributed virtual environment, network simulation, multi-sensory traffic, QoS.

1. INTRODUCTION
The future Internet will have to carry a wide range of applications, and many of these will incorporate new type of traffic. There has been recent interest in the transmission of multimodal information over the internet [1], and in particular the transmission of haptic information [2][3]. Haptic is from the word in Greek "haptikos", and concerns the sense of touch and force feedback through the human sensory system. 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. By definition, a virtual environment (VE) is a space that provides users with the illusion of acting in a real world. However in addition to audio and visual information, the provision of haptic feedback (the sense of touch) can profoundly improve the way we interact with virtual environments. Systems that support interfaces between a haptic device and a virtual environment are called Haptic Virtual Environments (HVEs). 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. In distributed HVEs (DHVE) for remote collaborations, the haptic device is separated from the virtual environment and remotely affects and manipulates it. In DHVEs, one or more users may interact with the virtual environment, and possibly with other users with haptic devices. In collaborative DHVEs the users take turns in manipulating the virtual objects while in co-operative DHVEs they can simultaneously modify them [4].

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. Studies have shown that the haptic experience deteriorates as network-induced packet delay and packet jitter increases beyond 30ms and 2ms respectively [2][3]. However, it is recognized that the performance of multimedia traffic can be improved by using QoS architectures that reduce these network impairments [5], and it is therefore expected that the performance of DHVE-based applications can also be enhanced by applying QoS mechanisms such as Diffserv [6].

A number of systems have been developed specifically for collaboration, including DIVE, CALVIN, and COVEN [7]. Some researchers have attempted to characteristic the network

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parameters for medical applications. In [8] 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). They use a nanoManiputor as a haptic device which integrates 3D graphics and force feedback to give a virtual environment interface to Scanned Probe Microscope (SPM). 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: 1. First In First Out, (FIFO), 2. Random Early Detection (RED) and 3. Class Based Threshold (CBT). Under RED, packets are randomly dropped from a queue with the probability of a packet being dropped at any given time being a function of the average length of the queue in the recent past. CBT provides isolation between traffic classes by maintaining separate threshold for each class. 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.

The majority of the preceding works have not considered effectively transmission of haptic traffic by applying QoS mechanisms such as DiffServ. Our study has been conducted with both experimental and simulation models in order to study the network QoS characteristics required for haptic traffic. The contributions of the work presented in this paper are: (i) a new peer-to-peer DHVE application in order to generate haptic traffic. (ii) In addition, a custom OPNET PDF model [2] has been developed and used in the simulations in order to allow us to examine large-scale haptic traffic, (iii) an empirical investigation of the QoS parameters used for haptic traffic transmission over a QoS–enabled IP network, (iv) improvement on transmission of haptic traffic by using Class Based Weight Fair Queue (CBWFQ) is also presented. The major research objective is therefore to reduce haptic traffic delay and jitter in distributed multi-sensory environments. The challenge is to apply QoS to this type of traffic and ensure its effective transmission in real time. Finally, we conclude this paper by stating our findings and future work.

2. DISTRIBUTED HAPTIC VIRTUAL ENVIRONMENT ARCHITECTURES

DHVEs support interfaces between multiple haptic devices and multiple virtual environments regardless of geographical constraints. The force feedback device used in this paper is the PHANToM desktop [9] from SensAble Technologies Inc. It 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 [9]. Contact with virtual objects is simulated by computing the force that resists the haptic device's Haptic Interface Point (HIP) from penetrating the virtual object's surface. This approach uses a proxy that transforms the HIP and is referred to as the Surface Contact Point (SCP). 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.

We use a Peer-to-Peer architecture as a DHVE system 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.

2.1 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 then other traffic types.

Table 1. DHVE haptic traffic versus other service types network parameters summary [2][3][[10][13][15]

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.

2.2 Experiment and Simulation Approaches

Figure 1 shows the approach taken. Haptic traffic was first captured in an experimental test bed, and the subsequent, traffic patterns analyzed and a custom OPNET PDF model created [2]. 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.

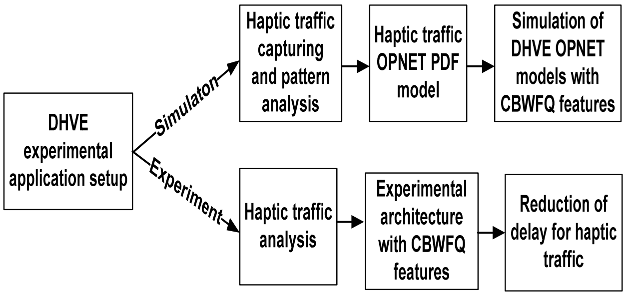

Figure 1. Experiment and simulation approaches to obtain the results in section 3 and 4.

3. EXPERIMENTAL ARCHITECTURE

In Figure 2, there are four computers involved in the experiment and connected through a bottleneck Ethernet link. The gigabit link is running on limited bandwidth of 10Mbps through the two Cisco routers A and B. We use Matlab Simulink, and the proSENSE toolbox from HandshakeVR [11] to develop our experimental system. In operation, PCs 1 and 2 are running DHVE Matlab applications. PCs 3 and 4 function as background traffic generators for the bottleneck link. The haptic traffic is given various CBWFQ weights in contrast with a constant background traffic weight. Figure 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 (HIPs). 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, PC 1 and PC 2 are pushing virtual objects which are 3D cubes in a virtual environment. Force is generated when PHANToM is touching the virtual cube. This force data together with the HIP and virtual objects' (3D cubes) positions are transmitted from PC1 to PC2 and vice versa. The majority of the other architectures have concentrated on synchronization of positions (haptic device or virtual objects). The peer-to-peer architecture presented here further extends this to enable force interaction between two users. Thus, the force data is sent over to remote peer in addition to the position information. The traffic flowing between all the computers are captured by using the IP Traffic [12], this was found to require 736 kbps for haptic traffic in each direction. Subsequently, we have created PDF models in OPNET [13] and use the PDF model to simulate haptic traffic with multimedia traffic sources.

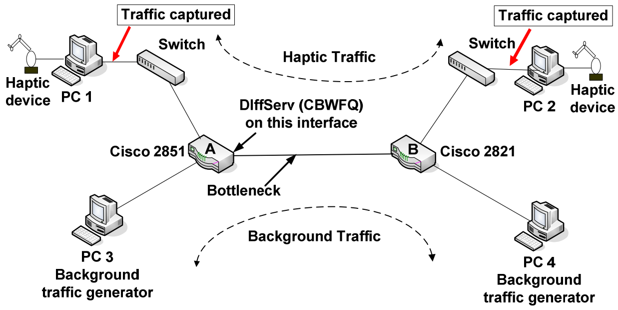

Figure 2. Experimental model of distributed peer-to-peer architecture

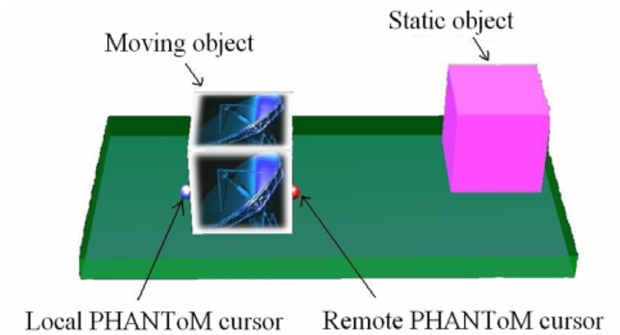

Figure 3. Snapshot of the implemented collaborative haptic virtual environment

3.1 Haptic Traffic Queue Configurations

DHVE traffic is classified by using Class Based Weight Fair Queuing (CBWFQ) from Cisco systems [14]. CBWFQ allows users to define the classes used in WFQ. The classes can be determined by protocol, Access Control Lists (ACLs), IP precedence, or input interface. Each class can be allocated different bandwidth guarantees in terms of its scheduler queue weight. This approach allows greater control of the haptic traffic together with other traffic. Figure 4 shows the processing applied to haptic traffic packets at the ingress into an interface and going through classifier and scheduler. The priority queue is served as long as it contains packets in the queue; the CBWFQ queues are then served in proportion to their weights. When CBWFQ queues have consumed any reserved bandwidth or become empty, the best effort queue is then served.

Figure 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 Figure 2. The haptic traffic class is set with CBWFQ weights of 0, 1, 5, 10 or 30. The background traffic class is set to have a weight of 1 throughout the test. Background traffic class has been allocated a guaranteed bandwidth of nearly 1Mbps. In order to improve the haptic traffic transmission under background traffic, the CBWFQ weight of the haptic traffic class is varied. Haptic class weight was not set higher than 30 because after that the delay is almost zero. This is because the CBWFQ has guaranteed enough bandwidth (736 kbps in our application) for haptic traffic. Background traffic percentage is calculated with the ratio of 10Mbps. For example, a 10 percent of background traffic will therefore generate 1Mbps from the Router A to Router B.

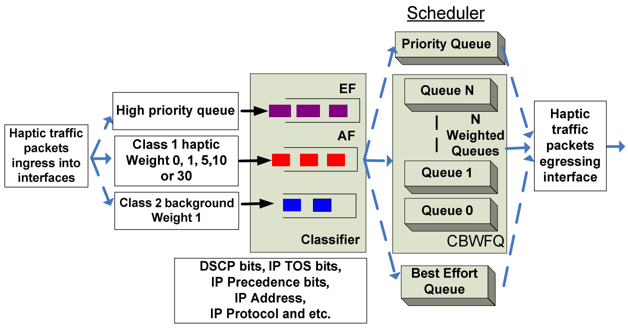

Figure 4. Cisco router Diffserv treatment for haptic and background traffic packets

4. DHVE SIMULATION MODEL

The network simulator OPNET Modeler was used to simulate Distributed Haptic Network environment. As there was no generalized distribution model that is able to represent haptic traffic in OPNET, a custom Probability Density Function (PDF) model was created. Details of this model are presented in [3]. In order to customize a simulation haptic network model, empirical haptic traffic is captured from the test bed, analyzed and then the OPNET PDF model is created. This is then applied as traffic in the network simulation. Figure 5 shows eighteen PCs connected with two switches and routers. The two routers A and B are connected with a PPP E1 link in order to study the effect of WFQ on haptic traffic. The PPP link creates a bottleneck between the routers. Background traffic builds up traffic congestion for router A and this permits traffic engineering techniques such as WFQ to be analyzed at the egress interface of router A. The other network links are 100Mbps. The Haptic 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, there are PCs running video, audio, FTP, Email, HTTP and Database applications as multimedia traffic flows. In this case, video and audio has been set with streaming traffic. The system is running with Weight Fair Queuing (WFQ) enabled in the output interface of router A as shown. WFQ dynamically classifies network traffic into individual flows and assign each flow a fair share of the total bandwidth. Unlike priority queuing, each flow will be serviced in according to their weight. The weight assigned to haptic traffic is then increased in steps. Additionally, a Low Latency Queue (LLQ) provides a priority queue function which is equivalent to Diffserv's EF queue.

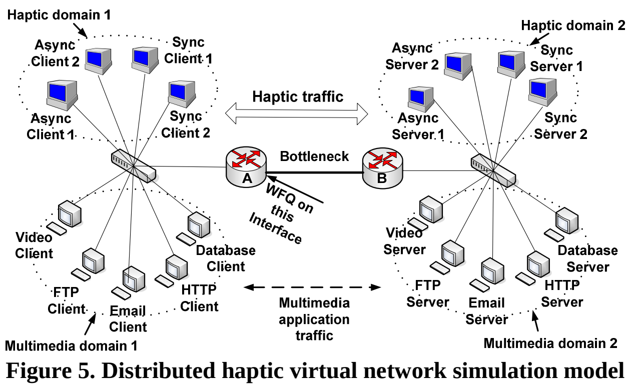

Figure 5. Distributed haptic virtual network simulation model with audio, video, ftp, http and database applications

5. EXPERIMENTAL AND SIMULATION RESULTS

5.1 Experiment Results

Figure 6 shows the experiment result when haptic traffic is allocated CBWFQ bandwidth weights of 1, 5, 10 and 30. The result shows that when the haptic traffic is given higher bandwidth, the packet transit delay is reduced. In Figure 6, haptic traffic end-to-end delay increases to 200ms whenever background traffic increases and the haptic traffic is under Best Effort treatment. This means that the router A in Figure 3 has not been set with any QoS mechanisms. When CBWFQ is employed, the delay of haptic traffic is reduced from 200ms (best effort,) to less than 1ms (CBWFQ weight=30) under the background load of 95% load. Setting the CBWFQ haptic weight=1 with a guaranteed bandwidth of 1 Mbps results in a significant improvement over best effect, and setting CBWFQ haptic weights of 10 and 30 can definitely reduce the delay further as shown.

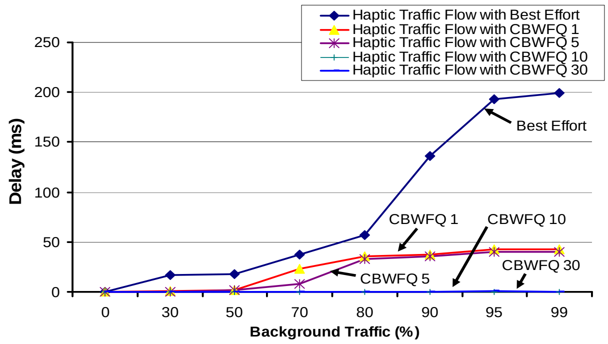

Figure 6. Haptic traffic end-to-end delay versus background with different WFQ weights at egress interface of router A

5.2 Simulation Results

This section investigates the haptic traffic characteristic with WFQ enabled on output interface of router A in Figure 5. The simulation results obtained are the end to end delay of one of the haptic traffic flows as shown in Figure 7. The results are obtained by setting different weights for the traffic flowing through the output interface of router A. The WFQ weight on x-axis is ranging from best effort (WFQ=0) to WFQ weight = 100. The Y-axis is the end-to-end delay of the haptic traffic. Initially, the best effort IP network caused end-to-end delays in the haptic traffic of 600ms. However, this delay is improved by applying DiffServ in the network model. It can be observed that the end-to-end delay has decreased from 600ms (WFQ weight = 0) to 13ms (WFQ weight = 100). The delay is further reduced to 9ms with the Low Latency Queue (LLQ) enabled on the interface. The result shows that the implementation of WFQ mechanism improves the QoS provided to the haptic traffic.

Within the distributed network, the haptic effective throughput is affected when there is a bottleneck in the network. Figure 8 shows this throughput at the Ethernet layer, captured at receiving end of the Async Server 1 in Figure 5. The result is obtained by running different WFQ weights for the haptic traffic. It shows the reduction in throughput when WFQ weight is below 60. From the observation of Figure 8, it is clear that the distributed network will need to spare 60% of total bandwidth of the T1 link. The haptic packets are has 64 bytes, which become 92bytes at Ethernet layer.

Therefore, the total throughput at the Ethernet layer is 92*1000*8=736Kbps. This is closely matched to the values in Figure 8.

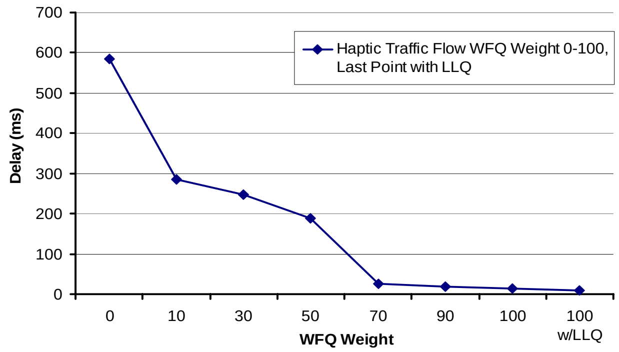

Figure 7. Haptic traffic end-to-end delay with different WFQ weights

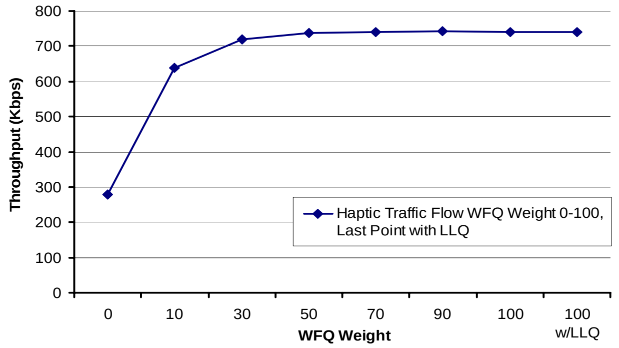

Figure 8. Haptic traffic throughput with different WFQ weights

5.3 Discussion of Simulation and Experiment Results

Sections 5.1 and 5.2 have presented the experimental and simulation results respectively. The end-to-end delay of the simulated haptic traffic decreases to 20ms when the WFQ weight is 70. However, the experiment result shows that the end-to-end delay drops to 40ms when CBWFQ weight = 1. This is because the simulation model has more traffic sources than the experiment test bed. In addition, CBWFQ guarantees bandwidth when given a certain amount of bandwidth in which haptic traffic has exclusive use. The haptic traffic is therefore able to improve its transmission quality if given a minimum amount of network bandwidth. This is shown in previous sections for both experiment and simulation results. From experiment, the user haptic perception has been improved when there is CBWFQ enabled in the network as compared to best effort service. We have also studied the consequence of using DSCP for haptic traffic as a shown in Table 2. Thus, the haptic traffic is studied for maximum end-to-end under different AF and EF of DSCP Marking. 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 suitable to be used in haptic traffic transmission. The maximum end-to-end delay also depends on the type of link used and the traffic loading. In this case, we used haptic traffic, real time audio and video streaming traffic plus the background traffic in our simulation model.

Table 2. Maximum end-to-end delay of haptic traffic by using different DiffServ Code Point (DSCP) AF and EF marking. Note: BE – Best Effort, AF – Assured Forward, EF – Expedited Forward, link T1 – 1.544Mbps, and link T3 – 45Mbps, loading 95% of the links.

DSCP	Haptic Traffic End-to-end Delay (ms)	
	T1	T3
BE	2701	1676.39
AF11	2174	224.2618
AF12	2174	224.2618
AF13	2174	224.2618
AF21	8.782	1.1846
AF22	8.782	1.1846
AF23	8.782	1.1846
AF31	6.384	1.2066
AF32	6.384	1.2066
AF33	6.384	1.2066
AF41	6.178	1.1603
AF42	6.178	1.1603
AF43	6.178	1.1603
EF	6.107	1.139

In Figure 8 above, we show that the haptic traffic has a throughput of 736kbps. Therefore, it is important to have a minimum bandwidth of above 736kbps in order for the haptic traffic to be effectively transmitted. This has also shown as refer to experiment result in Figure 6. Based on our findings, we proposed a DSCP marking scheme for haptic traffic. The requirement for using haptic traffic in a managed network by the network administrator is proposed in Table 3. The haptic class is proposed to have a DSCP marking of EF. The haptic traffic is comparable to telephony or video classes but it is very sensitive to jitter [5][16].

Table 3. Proposed haptic class with DSCP marking scheme in addition to DiffServ service classes and DSCP marking scheme in [15]

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

6. CONCLUSIONS AND FUTURE WORK

We presented in this paper a novel study by using experiment and simulation models to run distributed haptic applications under IP QoS enabled architecture. The work involves studies of haptic traffic under best effort IP network and DiffServ network. The work uses WFQ and CBWFQ as queue scheduler in the DiffServ network. The end-to-end delay and queue size of haptic traffic in the simulation model has been reduced by using WFQ and with implementation of Low Latency Queue (LLQ). Haptic throughput in simulation model has increased in corresponding to increase of WFQ weight. In the experiment network model, the end-to-end delay of haptic traffic has decreased from 200ms (best effort) to 40ms (CBWFQ=1) by running haptic application in DiffServ network. Both simulation and experimental results prove that transmission of haptic traffic has been improved with implementation of WFQ and CBWFQ respectively. Our simulation model can be used to simulate haptic traffic in large scale packet switched IP network. This work leads to a conclusion that WFQ and CBWFQ in DiffServ packet switched network has improved network performance of the haptic traffic by properly setting of the DifferServ DSCPs and scheduler. Subsequently, a haptic traffic class with DSCP marking scheme is proposed. In the future, we will conduct haptic user perception test under DiffServ IP QoS network with multiple users. In addition, we will study the application of Weight Random Early Detection (WRED) for the haptic traffic under congestion control.

7. ACKNOWLEDGMENT

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