Network AdaptiveFlow Control Algorithm for Haptic data over the Internet–NAFCAH

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Abstract. This paper deals with the transfer of real time haptic data over the Internet. Some interested transport protocols have already been proposed for the transport of real time haptic data. This paper presents the related work on haptic data transferring. A new network adaptive flow control algorithm is proposed. The new algorithm combines most of the known flow control algorithms while taking into account the network conditions of the Internet and the significant haptic events.

Keywords. Haptics, Tele-Haptics, Transport protocols, Teleoperation, Interative applications, Real time Protocol, flow control, congestion control.

1 INTRODUCTION

Real time data were considered until recently only video and audio data. With the optimization of telerobotics and the improvement of Internet status, a new kind of data made its appearance the last decade. This is tele-haptic data. With the word haptics we refer to the tactile and kinesthetic human sense. As human population grows older, the need for teleoperation is getting bigger. With the help of tele-haptics some risky jobs, such as nuclear disposal and wreckage exploration could be made with great safety. Furthermore, applications as tele-surgery, tele-mentoring, haptic video games, and augmented reality are only few examples of the many sectors of our daily life that tele- haptics could be applied to.

The main obstacle that impedes tele-haptics from flourishing is the delay and the jitter that is being encountered in the Internet. Several congestion/flow control algorithms have been proposed for the limitation of the negative effects of the delay and jitter. Some of them are the TCP congestion window[1], the Additive Increase/Multiplicative Decrease AIMD[2], the Rate Based Congestion Control RAP [3], and the TCP Friendly Rate Control (TFRC) [4], and the variable Inter packet Gap (IPG) [5].

Apart from the common congestion control algorithms some rather interesting technics intent to reduce the transfer rate of the haptic stream such as the packetization intervals [6], the differential coding with quantization [7], the haptic event prioritization [8], the dead-reckoning [9] and the perception based compression using Kalman filters [10].

Furthermore, the adaptive buffering [9], the haptic packet prioritization [11] and the wave variables [12] try to mitigate the jitter and the delay of the network.

The rest of the paper is organized as follows. Section 2 presents the related work on congestion/flow control algorithms that could be applied to haptic applications. and describes network conditions that should be fulfilled for a satisfying QoE. Section 3 analyzes the new proposed flow control algorithm for tele-haptic applications. Section 4 presents graphical representations of experimental data.Finally section 5 identifies conclusions and future work.

2 RELATED WORK ON CONGESTION/FLOW CONTROL ALGORITHMS

Lot of research has been done for the mitigation of the negative effects of the network delay and jitter. One way to avoid congestion is by minimizing the transmitted haptic packets when delay and jitter show increasing signs[5]. Another method tries to minimize the transmitted packets by forcing the receiver to predict the packets that hasn't receive[10]. A further technique transmits only the packets that produce haptic feedback perceptible form human senses[9]. Other methods try to compress the haptic data with lossy data reduction techniques such as the quantization and the differential coding [13]. Furthermore, some researchers send the haptic packets with different priorities[8], the most important packets are sent with higher priority and more reliable than other packets. One more method for minimizing the transfer rate is the packetization intervals [6], where a number of packets are grouped together in a frame and sent to the receiver as a packet.

Each of the above techniques presents some advantages regarding bandwidth, packet loss, and jitter at the expense of precision and the average delay. Depending on the application most of the above techniques improve Quality of Experience (QoE) of the user at specific network conditions.

The preferred network conditions may vary from application to application. Many of the studies [14, 15, 16, 17, 18] conclude that the network condition should satisfy the limitation of Table 1, in order the QoE of the user to be satisfactory.

Table 1. QoS Requirementsfor Multimedia Streams [14, 15, 16, 17, 18]

	APPLICATIONS			
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

3 THE PROPOSED FLOW CONTROL ALGORITHM-NAFCAH

Since the network conditions of the Internet are time-varying, the algorithm that controls the transmission of the packets should be network adaptive. Apart from the adaptive transmission rate and bandwidth, priority should be enforced in the haptic packets. Some packets are more important than others. These packets should be sent with higher priority and more reliably. If the network conditions are deteriorating some packets with lower priority should not be sent at all. Another metric that should be network adaptive is the size of the transmitted packets. Techniques as the differential coding and the quantization, should modify their parameters, in order to change the packet size, and as a consequence the bandwidth of the haptic stream. The transmission rate of the packets should be network adaptive as well. If the network shows some little signs of congestion as increased delay, jitter and packet loss, then the transmission rate should be reduced in order heavy congestion to be avoided.

Apart from the maximum values of the network delay, jitter and packet loss of Table 1, intermediate values should be established, in order to escalate the QoE of the users. The maximum values should be escalated into three values. The first scale of these values is [0-max/3] that corresponds to perfect network conditions and the QoE should increase in order to reach its maximum value.The scale (max/3 –2*max/3] corresponds to fair network conditions where the QoE should increase slowly. The scale (2*max/3 –max] corresponds to acceptable conditions but with high possibility of diversion. The flow algorithm should try to avoid this diversion by keepingthe QoE steady. When network conditions are worse than the maximum allowable value of Table 1, the flow algorithm should lower the QoE rapidly, so as to avoid congestion. Base on the above assumptions the Network Adaptive Flow Control Algorithm for Haptic data – NAFCAH is proposed.

3.1 Network Adaptive Packet Priority

One way to reduce the transmission rate and bandwidth of the haptic stream is to reduce the packets that are being transferred. Packets with lower priority can sometimes be omitted in order to reduce the transfer rate and bandwidth. In [8] the haptic event priority is introduced. When the Haptic Interaction Pointer (HIP) of the haptic interface approaches a virtual object, the haptic packet shouldobtain the higher Event Priority *ep*.

Event priority ep.

When the distance *dis* between the HIP and the virtual object decreases, the event priority *ep* increases based on the equation (1) and depicted in Fig. 1. The event priority takes its maximum value *ep=1* when the HIP touches the virtual object.

$$ep = \begin{cases} 1 & ,dnet < dmax \\ 1/(n*dis+1) & ,dmax/3 < dnet < 2dmax \\ 1/(2*n*dis+1) & ,2dmax/3 < dnet < dm \\ 1/(3*n*dis+1) & ,dmax < d\imath \end{cases} \quad (1)$$

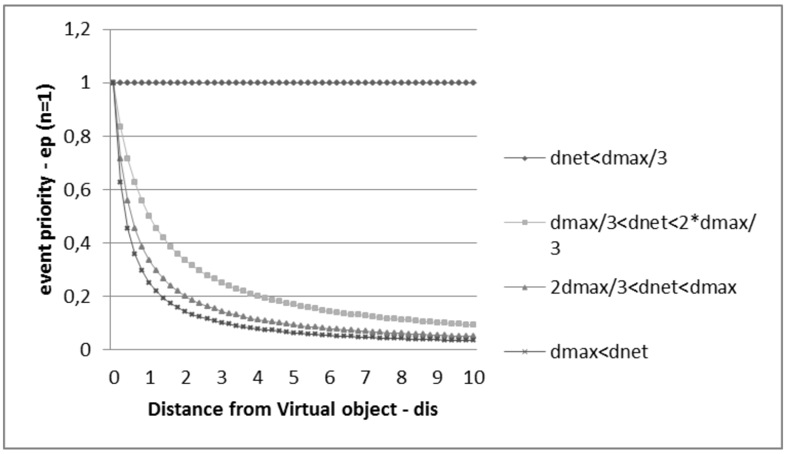

Fig.1. Event priority vs Distance from Virtual object

The higher the priority *ep* is, the higher the importance of the packet to be transmitted. When the priority *ep* is equal to 1, all the corresponding packets should pass the priority check and should be forwarded to the next priority process. The factor n>0, is set by the user and represents how steep curve of Fig 1 and 2 will be. The authors suggest n=1.When the factor *ep* is smaller to 1, the HIP doesn't encounterany impedance and the user relies on his/her visual sense to handle the haptic interface. The update rate in this case could be much lower than 1 KHz, equal to the necessary update rate for the vision sense 30 Hz. If network conditions are not adequate, intermediate packets should be dropped. Based on this observation, the update rate of packets that pass the event priority check *pr*is described in equation (2) and depicted in Fig. 2.

$$pr = 970 * ep + \quad (2)$$

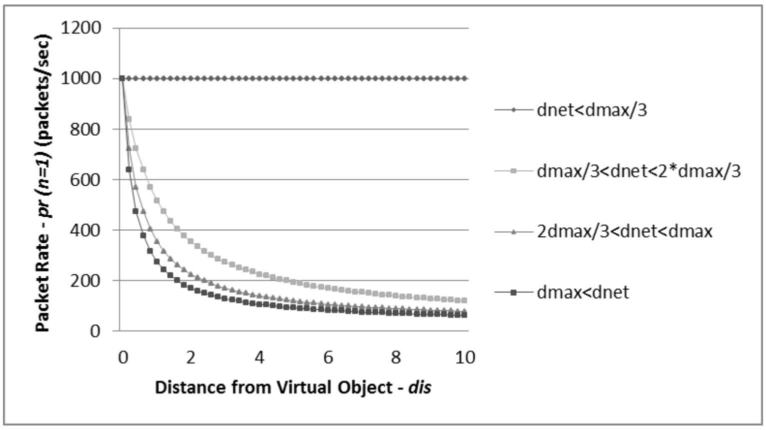

Fig.2. Packet Rate vs Distance from Virtual object

Perception priority *pep*.

Packets that don't generate perceptible haptic feelings to the user [9] should have lower Perceptible Priority *pep*. The perceptible priority *pep* is based on the dead-reckoning theory[9]. It uses the Weber's law of Just Noticeable Difference (JND) [19] to calculate the threshold ΔI. Equation (3) calculates the JND based on the stimulus intense I, that the haptic interface causes to the user. The constant κ is called the Weber fraction.

$$\Delta I = I * \kappa \tag{3}$$

When the haptic packet produces difference on the stimulus intense dI higher than ΔIthen the packet should transmitted with high priority. If the dI is lower the $\Delta I$the packet should have lower priority on the transmission.

In order the algorithm to be network adaptive, the Weber fraction κ_i should change according to the network conditions based on equation (4). When the network conditions deteriorate, the constant κ_i should increase in order fewer, but more important, packets to be transmitted. The factor $0<h<1$ is set by the user and represents how rapid the alteration of κwill be.The authors suggest h=0,01. The factor $\kappa_i$will try to change its value every time there is a feedback from the network for its network conditions.As far as the Weber fraction $\kappa_0$is concerned Karadogan et al. in[20] have shown that the Weber fraction should take values from $0.08<\kappa_0<0.3$ depending on the application. The smaller the Weber fraction is, the higher the QoE of the user.

$$\kappa_i = \begin{cases} \kappa_0 = 0.08 \\ \kappa_{i-1} * (1 - 2 * h) & ,dnet < dmax, \\ \kappa_{i-1} * (1 - h) & ,dmax/3 < dnet < 2dmax \\ \kappa_{i-1} & ,2dmax/3 < dnet < dm \\ \kappa_{i-1} * (1 + 2 * h) < 0.3 & ,dmax < d \end{cases} \quad (4)$$

The packets that pass the perception priorityfiltering, are passing to the next stage of the sorting.

Prediction priority *pp*.

Packets that can be predicted by previous packets [7] should obtain a lower Prediction Priority *pp*. Several Interesting studies [10] have shown that most of the transmitted packets could be predicted based on the previous data. If the movement of the HIP is linear the prediction is precise. The prediction unit is installed both at the sender and at the receiver. If the prediction unit at the sender calculates that the current packet could be predicted at the receiver from the last packets that were send, then the current packet is not transmitted. In order the algorithm to be network adaptive, apart from the identical predicted packets, predicted packets that are similar to the real packets could be excluded from the transmission. Again this algorithm should be based on Weber's law of the JND to decide which packets could successfully be predicted at the receiver side. If the predicted packet doesn't produce greater difference on the stimulus intense dI to the users from the real packetthan the threshold $\Delta I'$, then the packet is not transmitted, but it will be predicted on the receiver's side. In this case, the Weber fractionm_i could have different value from the variableκ of equation (3). Again the variable m_i should be changed according to the network conditions. The equations that decide which packets are predicted successfully are depicted in (5) and (6). The factor $0<j<1$ is set by the user and represents how rapid the alteration of m will be.The authors suggest j =0,01.

$$\Delta I_i' = I * m_i \quad (5)$$

$$m_i = \begin{cases} m_0 = 0.08 \\ m_{i-1} * (1 - 2 * j) & ,dnet < dmax/ \\ m_{i-1} * (1 - j) & ,dmax/3 < dnet < 2dmax, \\ m_{i-1} & ,2dmax/3 < dnet < dm \\ m_{i-1} * (1 + 2 * j) < 0.3 & ,dmax < d \end{cases} \quad (6)$$

3.2 Adaptive Transmission Rate

Interesting studies have shown that the network adaptive transmission rate of the haptic stream improves teleoperation[5]. The main obstacle in the variation of the transmission rate is the stable production of packages in the source. If the haptic interface produces update packets steadily and the sender fluctuates the sending rate, a buffer is necessary at the sender side to absorb the fluctuation[9]. The negative aspect of this technique is that if the haptic interface produces packets at very high update rate*ur*, usually 1 KHz[21], the sender should transmit its packets sometimes even fasterto compensates the previous lower rates. This even higher update rate often results in congestion and packet loss. In order to lower the update rate, an interesting proposal is to integrate a group of packets in a frame and sent them as a unified packet, a technic called packetization interval. Fujimoto and Ishibashi[6]have proven that a packetization interval of 8 packets that is sent every 8 ms improves the systems performance in overloaded networks.Another interesting study [11]has shown that the number of the integrated packetsnp_i should vary, depending on the network delay, in order not to overcome the maximum allowable delayd_{max}. Every packet that is integrated in the frame adds 1/*ur* sec of delay. If we take into account the network delay $d_{i,net}$, then the maximum number of integrated packets $np_{i,max}$ is:

$$np_{i,max} = (d_{max} - d_{i,net}) * ur \tag{7}$$

The delay of the network $d_{i,net}$can easily be extracted if ICMP packets are sent over the UDP protocol from the sender to the receiver. The number

$$np_i = \begin{cases} np_0 = 8 & \\ np_{i-1} - 2 > 0 & , dnet < dmax \\ np_{i-1} - 1 > 0 & , dmax/3 < dnet < 2 * dmax \\ np_{i-1} & , 2dmax/3 < dnet < dm \\ np_{i-1} + 2 < 8 & , dmax < d \end{cases} \tag{8}$$

3.3 Network Adaptive Quantization.

The bandwidth that a haptic stream absorbs,depends on two factors, the frame rate, that is determined from equation (8) and the size of the frame. The frame size could be reduced if differential coding and quantization [13] is enforced on the packets that are grouped in the frame. The technique that is recommended is the Differential Pulse-Code Modulation (DPCM). In case of a slow motion of the HIP, most of the haptic packets have similar values. The differential coding will produce smaller values than the original ones. Smaller values mean fewer bits. The quantization of the differentiate values could be made with variable quantization stepqs_i. The Adaptive Differential Pulse-Code Modulation (ADPCM) for haptic packets was introduced in [13]. Cyrus et al proposed to alter the quantization step according to the difference size. In this paper the authors propose to change the quantization step according to the network conditions. When the network conditions deteriorate the qs_i should increase in order fewer bits to berequired for thereconstruction of the original values. The $qs_i$is calculated based on equation (9). The factor $0<l<1$indicateshow rapid the alteration of qs_iwill be, in accordance to the network feedback. The authors suggest l=0,01.

$$qs_i = \begin{cases} qs_0 = 0.3 \\ \qquad qs_{i-1} * (1 - 2 * l), < dmax/3 \\ qs_{i-1} * (1 - l) \qquad ,dmax/3 < dnet < 2dmax \\ qs_{i-1} \qquad ,2dmax/3 < dnet < dm \\ qs_{i-1} * (1 + 2 * l) < 1 \qquad ,dmax < d \end{cases} \tag{9}$$

The initial quantization stepqs_0in [22]after experiment regarding Mean Opinion Score (MOS) is recommended $qs_0=0.3\ mm$.

The flowchart of Network Adaptive Flow Control Protocol -NAFCAH which is based on the above priorities and compressions is depicted in Fig. 3.

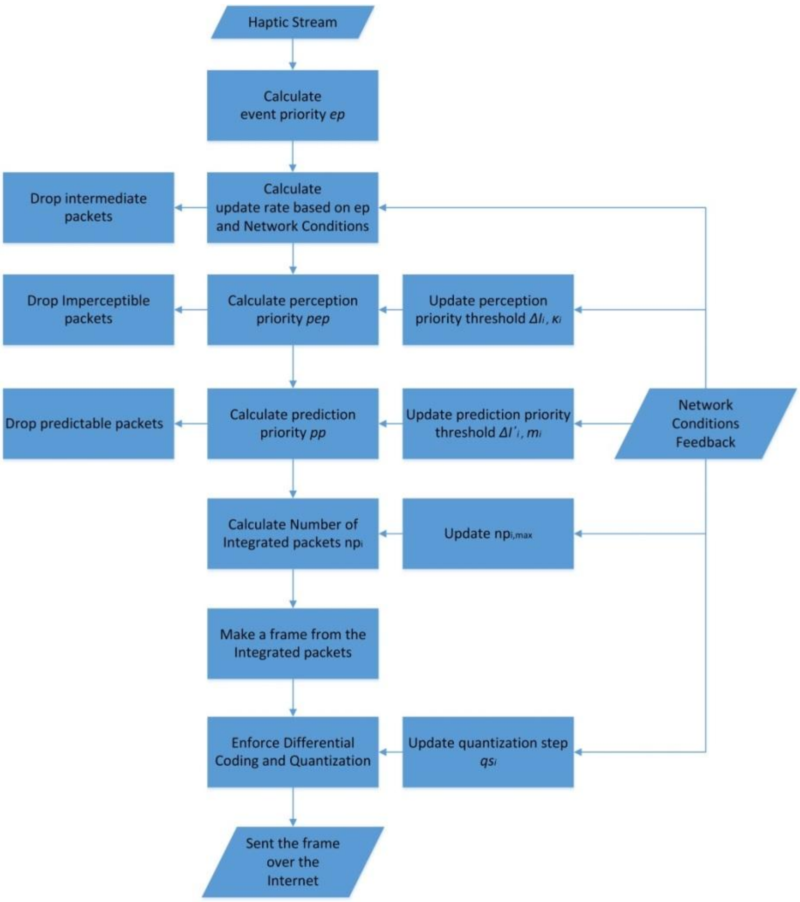

Fig.3. Flowchart of Network Adaptive Flow Control Protocol -NAFCAH

4 EXPERIMENTAL DATA

The authors in order to infer the network conditions of the Internetthey sent 3000 ICMP packets through Internet from Grevena to Thessaloniki, 170 km away from each other.Both clients were directly connected to the private optical network, GRNET[23].The results of these experiments are shown in Table 2 and in figure 4.

Table 2. Internet Network ConditionsBetween Thessaloniki- Grevena, Greece

CONNECTED CITIES	***AVG. DELAY (ms)***	***Standard DELAY Devia-tion(ms)***	***PACKET LOSS (%)***	***No. HOPS***
GREVENA – THESSALONIKH THROUGH GRNET	31.66	15.7	0.1	6

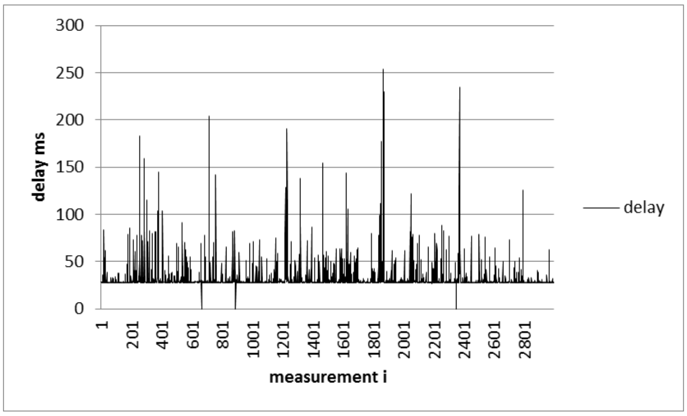

Fig.4. The network delay between Grevena – Thessaloniki, Greece.

The Weber fractions *κ*, *m* of the equations (4) and (6) from the above delay is depicted in figure 5.

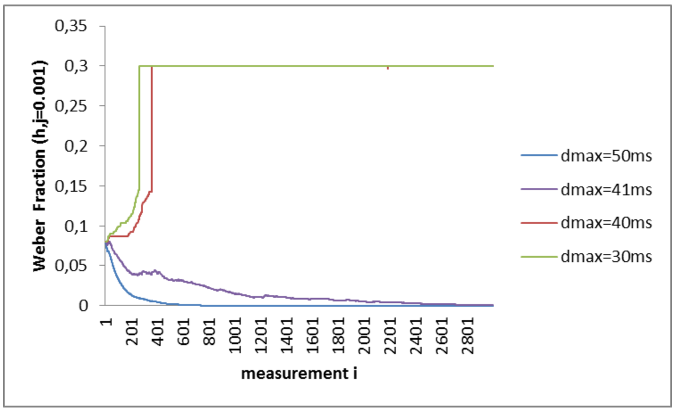

Fig.5. The Weber Fractions *κ, m* in relation to the network delay.

The Weber fractions start to decrease their value when we set *dmax=41 ms*.This means that *2*dmax/3= 27.33 ms*.The condition *dnet<2*dmax/3* is being satisfied 972 times, that's why the Weber fractions are decreasing for *dmax>41*.

The number of packets *np* of the equation 8 in relation to the network delay are depicted in Fig. 6.

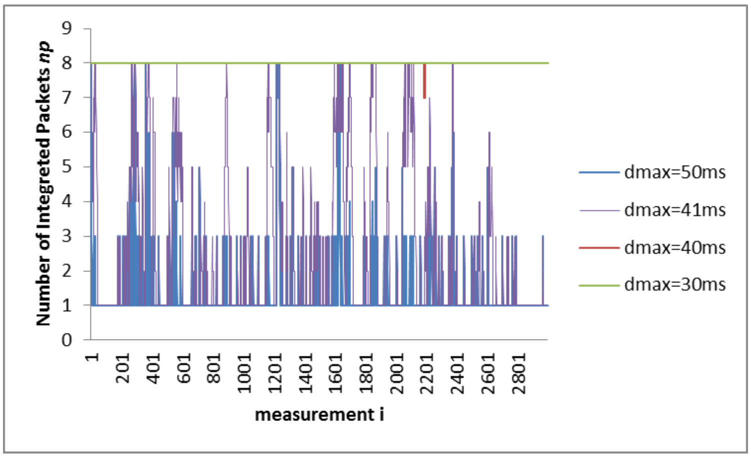

Fig.6. The number of packets *np* in relation to the network delay.

When the maximum desirable network delay *dmax* is lower or equal to 40 ms, the number of integrated packets is *np=8*. The *np*is decreasing when *dmax=> 41 ms* because the condition *dnet<2*dmax/3= 27.33 ms* is being satisfied 972 times.

Similarly the quantization step*qs*is changing according to the network delay based on equation (9) and is depicted in Fig. 7.

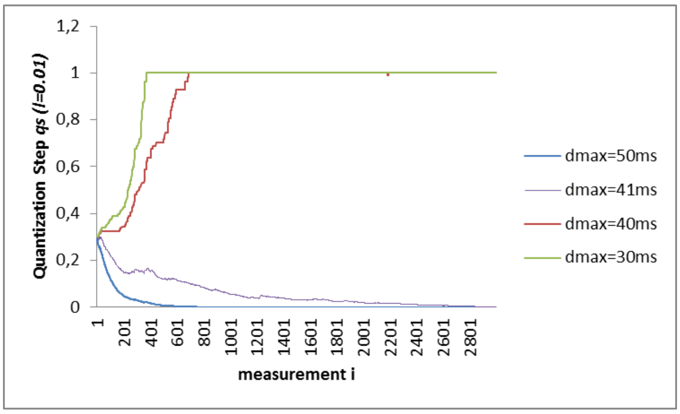

Fig.7. The Quantization stepin relation to the network delay.

The quantization step is decreasing when *dmax=> 41 ms* because the condition *dnet<2*dmax/3= 27.33* ms is being satisfied 972 times. Therefore the quantization step is increasing in order to maximize the QoE. When *dmax<=40 ms*, the condition *dnet<2*dmax/3* is never satisfied, therefore the quantization step is constantly increasing.

5 CONCLUSIONS AND FUTURE WORK

It is known that the network conditions of the Internet are constantly changing. The metrics such as the network delay, the jitter and the packet loss are not stable. In such a variable environment a flow control algorithm for transferring haptic data is necessary. In this paper a network adaptive flow control algorithm named NAFCAH is presented. It is a quit flexible algorithm where the user can set its sensitivity to the network variations. All the known congestion and flow control techniques have been enforced, in order to achieve the desired result. Packet priorities such as the event priority, the perception priority and the prediction priority are described and defined. Packetization Interval technique and lossy compression methods such as the Adaptive Differential Pulse-Code Modulation are enforced.

It has already been scheduled to evaluate the presented flow control algorithm in simulations and real world experiments. These experiments will have as a primary target to define the proposed values for the factors *n, h, j, l,*and the initial and the maximum values ofκ, *m*,*qs*that the user should set for the sensitivity of the flow control algorithm.

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