# An Empirical Model for Multi-Contact Point Haptic Network Traffic

# (Invited Paper)

Mamun Abu-Tair
The institute of Electronics, Communications and Information Technology
Queens University Belfast
Belfast, UK
m.abu-tair@qub.ac.uk

Alan Marshall
The institute of Electronics, Communications and Information Technology
Queens University Belfast
Belfast, UK
a.marshall@qub.ac.uk

## ABSTRACT

The emergence of force feedback haptic devices that can remotely interact with virtual environments presents a number of challenges to the underlying networks that have to support their interactions. One important issue concerns the characterisation of haptic traffic, particularly whenever multiple users remotely interact over a network such as the Internet. Previous research has characterised the traffic produced by single contact-point haptic devices when remotely interacting with a distributed haptic virtual environments (DHVEs). The research presented in this paper extends this work to consider the more complex traffic produced by haptic devices with multiple contact points, whenever interacting remotely with virtual environments. Such devices produce a rich mixture of different traffic streams that are interdependent but also characterised by the interactions of the individual users. The aim of the work presented here is to characterise the traffic generated by multi-point DHVE network connections. The approach taken develops an analytical model of DHVE traffic based on empirical measurements. Suitable probability distributions models are subsequently derived for each type of traffic. The results show that each traffic type exhibits either a Normal or a Weibull distribution. The results permit the development of a multi-contact point haptic traffic generator model which can then be used by simulation and analytical studies in order to examine how such interactive applications can be transmitted over different network situations and topologies.

## Keywords

Haptics, multi-point haptics, distributed haptic virtual environments, traffic characteristics.

## 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 [7, 3], and in particular the transmission of haptic information [12, 13]. Haptic environments are a relatively new subset of virtual reality, which are set to dramatically increase and improve upon the range of applications that can be supported in them. The provision of haptic feedback can profoundly improve the way humans interact with information and communicate ideas. Systems that support haptic interfaces conveying information from a virtual environment to a user’s fingers, hand or arm, are called haptic virtual environments (HVEs). In this context, haptic refers to the modality of touch and the sensation of shape and texture that an observer feels when exploring an object in a virtual environment.

Previous research [3, 12] 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. HVEs can be standalone or distributed. In a standalone HVE, both the haptic virtual environment and the haptic device reside on, or are connected to the same machine. In distributed HVEs (DHVEs) the haptic device is separate from the virtual environment and remotely affects and manipulates it. In DHVEs, one or multiple users may interact with the virtual environment, and possibly with other users with haptic devices. Users may take turns in manipulating a virtual object as in Collaborative Environments or may simultaneously modify the same object as in, for example, Cooperative Environments [4]. The DHVE provides the feeling of tele-presence for a single user and the feeling of both tele-presence and co-presence for multiple users. A DHVE application involves remote haptic operations over network connections. Today most haptic applications are standalone systems. Nevertheless, it is clear that the ability to provide distributed haptic applications across a universally accessible medium such as the Internet will increase their profile to a much wider range of users, and effectively transmitting haptic data in Distributed Haptic Virtual Environments (DHVEs) is therefore a promising research area for a wide range of new applications [2].

Haptic devices exist in different forms and can be classified according to the type of feedback they produce. There are two main types of haptic devices: force feedback and tactile feedback. Force feedback devices utilise people’s kinaesthetic sense, which is the information picked up at their joints and tendons. Tactile feedback devices stimulate people’s cutaneous sense by deforming the skin, typically at the fingertips. There are more specific classifications within these two basic device types. The force feedback devices can be divided into groups according to

*IMMERSCOM 2009*, May 27–29, 2009, Berkeley, USA.
ISBN # 978-963-9799-39-4

*Digital Object Identifier: 10.4108/ICST.IMMERSCOM2009.6455*
*http://dx.doi.org/10.4108/ICST.IMMERSCOM2009.6455*

their number of degree-of-freedom (DoF) and number of contact points. The DoF range is usually between 1 and 6. Figure 1a shows the 6 DoF PHANToM from SensAble Technologies Inc [11]. Most commercially available force feedback devices today provide a single point of contact, a notable exception being Immerson's CyberGrasp (Figure 1b), which provides 5 haptic contact points [6].

Figure 1. (a) PHANToM Omni 6DOF

Figure 1. (b) CyberGrasp

In single contact-point haptic devices the user interacts with virtual objects using the stylus which provides the user with a single contact-point of forced feedback. On the other hand, the multi-point contact haptic devices (e.g the CyberGrasp system) provide multiple points of force feedback by using many individual actuators that are arranged as an exoskeleton system over a tracking glove. Interactions with virtual objects therefore involve tracking multiple points of contact, termed "haptic interface points" (HIPs) as well as generation of the individual force and positions of the HIPs, and of the ensemble system.

Previous studies into DHVE interactions have investigated the effect of network impairments on the sense of human perception during DHVE interactions [3, 12] while [13] characterized a single contact-point haptic traffic flow over an IP networks. The key objective of these existing studies was to examine the performance of a single contact-point haptic device over various network conditions. This paper presents an empirically derived model that can be used to characterize the traffic flows associated with multi-point contact haptic devices when interacting in DHVEs and transmitted over IP-networks..

The rest of the paper is organized as follow: Section 2 describes the architecture of the haptic device used along with a description of the experiment configuration, and the data collection techniques. Section 3 introduces the methodology used to characterize multi-point contact haptic traffic. Section 4 presents and discusses the results, and section 5 concludes the paper.

## 2. EXPERIMENTAL SETUP

A key element to characterising haptic traffic flows is the type of the haptic device which generates the traffic. Single contact-point devices allow the user to haptically render, and hence interact with the virtual environment, with only one HIP . These kind of devices normally generate a single stream of traffic that consists of positional (and optionally force) information. On the other hand, multiple contact point haptic devises are more complex haptic devices which provide the user with a fuller sense of touch. The architectures of these kind of devices consist of multiple internal and external components that describe the states of each HIP and of the overall system. Each component generates its own information stream in order to provide the user with a more complete sense of touch experience. Moreover, the experiment setup and network architecture have a direct effect on the traffic characterization process. The following subsections describe the haptic device, the experiment configuration and the data gathering techniques used in this study.

### 2.1 The Device

The force-feedback haptic device used in the experimental testbed is a CyberGrasp system (Figure 1b). The CyberGrasp system is a multi-point contact haptic device by Immersion Corporation [6]. The CyberGrasp system consists of three components: CyberGlove, CyberGrasp actuators and position tracker. Figure 2 shows the CyberGrasp system's architecture. The CyberGlove component provides the host with the measurement of the joint angles of the fingers, hand, and wrist. In order to gather this information the CyberGlove components uses 22 sensors over the entire glove. This information is necessary for the host to display a graphical hand on the screen.

The second component of the CyberGrasp system is its actuators. The main responsibility of the CyberGrasp actuators is to provide force feedback to the user. The CyberGrasp's actuators fasten on the back of the user's hand and consists of an exoskeliton arrangement of five actuators which provide individual force feedback to each finger.

In addition to the CyberGlove and the CyberGrasp actuators components, the position tracker is an important component of the CyberGrasp system. The position tracker of the CyberGrasp system is a 6 degree-of-freedom tracking system which can track the position and orientation of the user's hand without restrictions, delay or lag. The position tracker consists of magnetic field transmitters and a sensor that can sense changes in the magnetic field to report position and orientation information.

These three component are connected to the CyberGrasp force unit. The CuberGrasp force unit manpiulates the data and sends/reciveds the information to/from the machine which hosts the virtual enviroment through the host link.

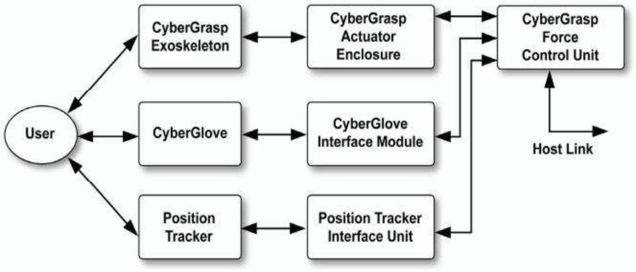

Figure 2 .CyberGrasp System Components [5]

### 2.2 The Experiment

As shown in Figure 3, the experimental environment involves three machines which are connected over a local network.

Machine A is connected to the CyberGrasp using a serial link and acts as a server which gatheres and manpulates the information from the CyberGrasp system's components. Machine B is a client and running the DHVE. Machine C monitors and captures the network traffic. In order avoid interference from other traffic sources, only haptic taffic is permitted on the test network. The DHVE consists of three objects, a virtual hand and two virtual spheres. The objective is to consider different kind of object's collisions which may occur at the virtual environment: (1) collisions between virtual hand and virtual object, (2) collisions between two virtual objects.

The experiment was performed with six different users. All users interacted with the same virtual environment under the same conditions. The users were asked to perform two main tasks in the experiment. The first task was to move one of the virtual objects from one place to another. The second task was to cause a collision between two virtual objects.

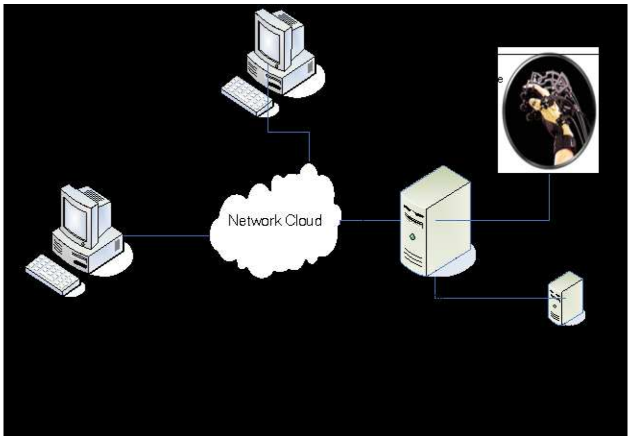

Figure 3. Experimental Setup

## 2.3 Traffic Collection and Analysis

Packet trace capture and analysis is a well-known technique for characterizing the traffic of networked applications. Many existing studies such as [8, 9] have used this approach due to its ability to capture the behaviour of individual users. This study uses packet traces to model the multi-point haptic traffic. For this purpose, a packet monitoring tool called "IP Traffic" [14], installed on machine C was used to capture the network traffic. The measured network parameters are throughput and packet delay. The captured traffic was then imported into statistical toolkits used to analyse the individual CyberGrasp component traces for each of the users. MatLab's stastical toolbox was then used to determine the most suitable probability distribution for each type of traffic. The methodology used to obtain this is described in the following section.

## 3. METHODOLOGY

The approach used to characterise each trace is based on [9], which has been used to characterise the traffic flows caused by TCP connections over the Internet . The technique has two main stages. The first stage derives various probability distribution functions for each of the CyberGrasp's component traffic types. Normal, Lognormal, Gamma, Extreme value and Weibull probability distributions were considered. These distributions are then parameterized using one or more constants obtained by fitting the distributions to each trace. Additionally, in order to provide an accurate estimation of the distribution bin's width the following equation used by Scott [10] was used to represent the data set.

$$w = 3.49\sigma_x n^{-1/3} \qquad (1)$$

Where $\omega$ is the bin width, $\sigma_x$ is the estimated standard deviations and $n$ is the number of instances.

In the second stage, we consider the Anderson-Darling (A-D) goodness-of-fit test [1]. The A-D test compares an observed cumulative distribution with an expected cumulative distribution function. The A-D test is based on the Kolmogorov-Smirnov (K-S) test. The A-D goodness-of-fit test is statistically defined as follows:

$$A^2 = -N - \sum_{i=1}^{N} \frac{(2i-1)}{N}.[\ln f(Y_i) + \ln(1 - f(Y_{N+1-i}))] \qquad (2)$$

Where $f$ is the cumulative distribution function of the specified distribution. The A-D test defines two hypothesis:

$H_0$ :the data follows the specified distribution;

$H_A$ : the data does not follow the specified distribution

In operation, a test statistic, $A^2$ is compared with a critical value ($\alpha$). If $A^2$ is greater than the critical value the hypothesis regarding the particular distribution form is rejected. The following section illustrates the results of the distribution fitting process for the different CyberGrasp system components.

## 4. EXPERIMENTAL RESULTS

As described in section 2.1, the CyberGrasp system has three traffic components. Each component establishes a TCP connection between the server (haptic device side) and the client (the DHVE host). Table 1 shows the packet size of each connection in the connection's side. Table 2, illustrates the mean inter-arrival packet time and the throughput of the haptic traffic for different users, respectively.

The CyberGrasp system synchronizes its individual traffic components by updating their statues at the same time, therfore it is to be expected that they will produce similar distributions. The results confirm that the inter-arrival packet time distributions of all of CyberGrasp's traffic components are similar to each other for individual user. For this reason this section presents the analysis of the CyberGrasp actuators component traffic model only.

Figures 4 and 5 show the Cumulative Distribution Function (CDF) and Packet Density Function (PDF) for the packet inter-arrival time of user1. The figures illustrate the different estimated distribution functions for this particular data.

*Digital Object Identifier: 10.4108/ICST.IMMERSCOM2009.6455*
*http://dx.doi.org/10.4108/ICST.IMMERSCOM2009.6455*

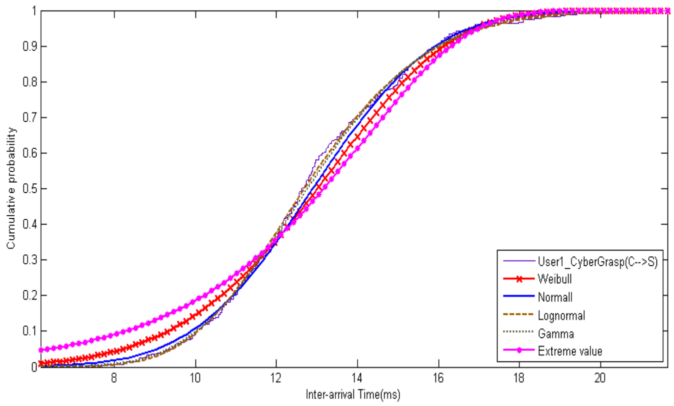

Figure 4. CDF of CyberGrasp’s inter-arrival time

It can be observed from Figures 4 and 5 that the CyberGrasp actuators component’s traffic fits well to the Weibull, Normal, Gamma, Extreme value and Lognormal distributions. Table 3 presents a summary of fitting process of the different distribution functions for different users. However in addition to the visual examination of the data set, the A-D goodness-of-fit is used to find the accuracy of the traffic model, table 4 shows the results of this test, and it can be observed that only the Weibull or Normal distributions pass the test for all users. As a result, the traffic of the CyberGrasp system’s components can be modelled using the Weibull or Normal distribution. However, the user’s behaviour of using the haptic device also has a major effect on the haptic traffic. Figure 6 shows the PDF of the CyberGrasp actuators component traffic estimated by the Weibull distributions.

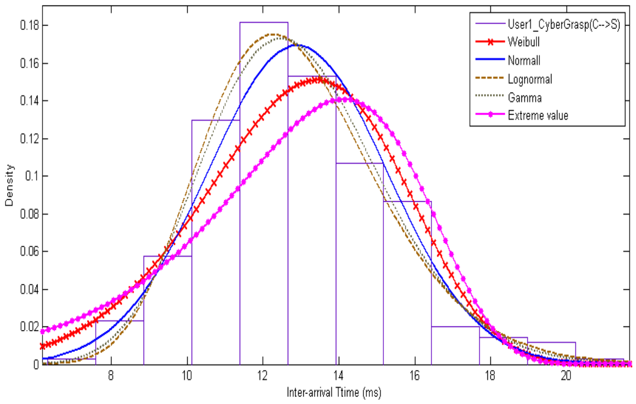

Figure 5. PDF of CyberGrasp’s inter-arrival time

Table 3 and Figure 6 show that the Weibull distribution’s parameters have different values. It can be observed that these values vary between 11.739 to 15.922, and from 4.9851 to 6.6351 with mean of 13.4118 and 5.828 for α and β, respectively.

According to these results, the most important paremeters (the packet size and the packet inter-arrival time) have been characterised. Consequently a generator for simulating multi contact point haptic devices can be implemented. For each haptic device in the expermient the traffic generator should employ three TCP connections on the server side and three TCP connections on the client side. For each connection the packet inter-arrival times should follow Weibull or Normal distributions with the spcific values for the distribution’s parameters conducted in this study. Morover, the packets size of each connection should follow the values given in Table 1.

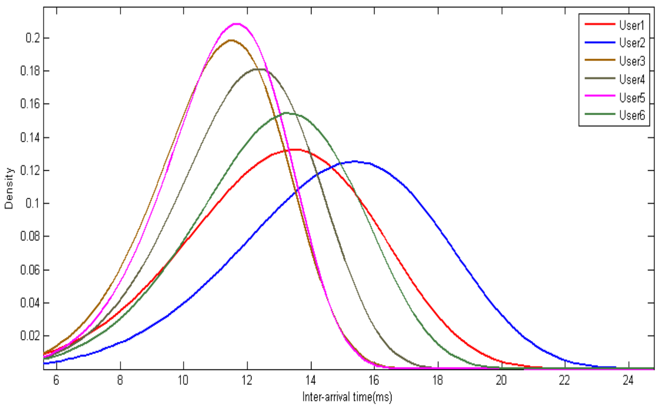

Figure 6. PDF of CyberGrasp’s inter-arrival time for different users

## 5. CONCLUSIONS

The key contribution of this paper is the development of an empirical model of the network traffic produced by haptic devices with multiple contact points. The model consists of a number of probability distributions for each component of the multiple contact haptic device. This achieved by analysing the traffic profiles obtained from a series of user tests involving haptic devices (Immersion’s CyberGrasp) interacting with a distributed haptive virtual environment (DHVE) over an IP-based network.

The results of the characterisation process of the multiple contact point haptic traffic has shown that the packet inter-arrival times of each traffic component (CyberGlove, CyberGrasp actuators and position tracker) exhibits either Normal or Weibull distributions. By analysing the traffic’s profile of six different users, we have shown that the multiple contact point haptic traffic can be modelled by Weibull distribution with values of 13.4118 and 5.828 for α and β parameters, respectively, or by using Normal distribution with value of 12.4428 and 2.3625 μ and σ parameters, respectively. Moreover, Table 1 shows the packet size of each multiple contact point haptic device components which needs to be used with the model.

The resultant model can be used to simulate the traffic generated by multiple haptic devices of this nature, and this in turn may be used to predict the network traffic load presented by these new types of devices and applications, as well as identifying the level of provisioning and support (for example in terms of quality of service (QoS)) that the network needs to provide for this class of multimodal traffic.

## 6. ACKNOWLEDGMENTS

The authors gratefully acknowledge the support and financial assistance provided by the UK EPSRC, under the project EP/E062350 "Network Architectures for Distributed Haptics virtual Environments (HAPNet)"; the assistance of Immersion corporation is also gratefully acknowledged.

## 7. REFERENCES

[1] Anderson, T. W. and Darling, D. A., “Asymptotic Theory of Certain "Goodness of Fit" Criteria Based on Stochastic

*Digital Object Identifier: 10.4108/ICST.IMMERSCOM2009.6455*
*http://dx.doi.org/10.4108/ICST.IMMERSCOM2009.6455*

Processes”, The Annals of Mathematical Statistics, Vol. 23, No. 2 , PP. 193-212, 1952

[2] Buttolo, P., Roberto O. and Blake, H., “Architectures for Shared Haptic Virtual Environments”, special issue of Computer & Graphics, vol. 21, No. 4, PP. 421-429, 1997.

[3] Hikichi, K., Morino, H., Arimoto, I., Sezaki, K., Yasuda, Y., “The Evaluation of Delay Jitter for Haptics Collaboration Over the Internet”, IEEE Global Telecommunications Conference, GLOBECOM, vol. 2, PP. 1492-1496, 2002.

[4] Iglesias, R., García-Alonso, A., Marshall, A., Yu, W., Gutiérrez, T. and Casado, S., “Simultaneous Remote Haptic Collaboration for Assembling Tasks”, ACM Multimedia Systems Journal, Vol 13, No. 4, 2008.

[5] Immersion corporation: CyberGrasp™ User’s Guide, 2007, http://www.immersion.com/3d/docs/CyberGrasp_v2_rev3_1207.pdf

[6] Immersion corporation: http://www.immersion.com/3d/products/

[7] Jeffay, K., Hudson, T. and Parris, M., "Beyond Audio and Video: Multimedia Networking Support for Distributed Immersive Virtual Environments", Proceedings of the 27th EUROMICRO Conference, Warsaw, Poland, PP. 300-307, 2001.

[8] Mah, B., “An Empirical Model of HTTP Network Traffic", Proceeding of INFOCOM '97, Kobe, Japan, April 1997.

[9] Paxson, V., “Emprically Derived Analytic Models of Wide-Area TCP Connections”, IEEE/ACM Transactions on Networking, vol. 2, No. 4, PP. 316–336, 1994.

[10] Scott, D., “On Optimal and Data-based Histograms”, Biometrika, vol. 66, No. 3, PP. 605-610, 1979.

[11] SenSAble Technologies. http://www.sensable.com

[12] Souayed, R., Gaiti, D. , Yu, W., Dodds, G., and Marshall, A. "Experimental Study of Haptic Interaction in Distributed Virtual Environments", Eurohaptics 2004, Germany, 5-7 June 2004

[13] Yap, K.M., Marshall, A., Yu, W., Dodds, G., Gu, Q. and Souayed, R., “Characterising Distributed Haptic Virtual Environment Network Traffic Flows”, Proceeding of IFIP Network Control and Engineering for QoS, Security and Mobility, 14-17 Nov 2005, France Telecom.

[14] ZTI Telecom, http://www.zti-telecom.com/pages/main-ip.htm

**Table 1. CyberGrasp system traffic components packet sizes**

| | Server→Client | Client→Server |
|---|---|---|
| **Position Tracker** | 121 Byte | 72 Byte |
| **CyberGlove** | 264 Byte | 72 Byte |
| **CyberGrasp** | 72 Byte | 442 Byte |

**Table 2. Throughput and mean inter-arrival times**

| | | **Position Tracker** | | **CyberGlove** | | **CyberGrasp** | |
|---|---|---|---|---|---|---|---|
| | | **Mean inter-arrival time (ms)** | **Throughput (Kbit/s)** | **Mean inter-arrival time (ms)** | **Throughput (Kbit/s)** | **Mean inter-arrival time (ms)** | **Throughput (Kbit/s)** |
| **User1** | **S → C** | 12.9515 | 153.8606 | 12.95197 | 70.5192 | 12.93704 | 41.96077 |
| | **C → S** | 12.91708 | 42.00533 | 12.92073 | 42.01084 | 12.90182 | 257.6291 |
| **User2** | **S → C** | 11.1473 | 180.4402 | 11.14628 | 82.70084 | 11.14434 | 49.21197 |
| | **C → S** | 11.13609 | 49.24507 | 11.13569 | 49.24511 | 11.12624 | 302.1313 |
| **User3** | **S → C** | 11.9212 | 167.591 | 11.91825 | 76.81193 | 11.90985 | 45.70777 |
| | **C → S** | 11.91989 | 45.71464 | 11.90923 | 45.71354 | 11.90887 | 280.5823 |
| **User4** | **S → C** | 10.88343 | 187.1543 | 10.87818 | 85.77861 | 10.87631 | 51.0431 |
| | **C → S** | 10.86799 | 51.07058 | 10.88113 | 51.06927 | 10.86836 | 313.3685 |
| **User5** | **S → C** | 14.68953 | 135.5242 | 14.70562 | 62.11474 | 14.68573 | 36.9623 |
| | **C → S** | 14.54628 | 37.1096 | 14.55686 | 37.10942 | 14.5392 | 227.05 |
| **User6** | **S → C** | 13.05872 | 154.6587 | 13.05836 | 70.88471 | 13.05562 | 42.18055 |
| | **C → S** | 12.97234 | 42.22281 | 12.97668 | 42.22518 | 12.98066 | 258.9235 |

**Table 3. Parameters for each traffic model distribution**

| | | Weibull | | Normal | | Gamma | | Extreme Value | | Lognormal | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | α | β | σ | μ | A | β | σ | μ | σ | μ |
| **User1** | **S → C** | 13.963 | 5.4786 | 2.4078 | 12.952 | 29.637 | 0.43701 | 2.7003 | 14.209 | 0.18463 | 2.5443 |
| | **C → S** | 13.91 | 5.6439 | 2.3489 | 12.920 | 30.750 | 0.42018 | 2.6020 | 14.138 | 0.18155 | 2.5424 |
| **User2** | **S → C** | 11.964 | 6.6351 | 2.0172 | 11.146 | 27.784 | 0.40118 | 1.74 | 12.104 | 0.19627 | 2.393 |
| | **C → S** | 11.953 | 6.6290 | 2.0164 | 11.135 | 27.754 | 0.40129 | 1.7404 | 12.093 | 0.19639 | 2.3920 |
| **User3** | **S → C** | 12.750 | 6.4158 | 1.9840 | 11.918 | 34.701 | 0.34345 | 2.0856 | 12.908 | 0.17338 | 2.4635 |
| | **C → S** | 12.740 | 6.4147 | 1.9803 | 11.909 | 34.796 | 0.34225 | 2.0860 | 12.897 | 0.17312 | 2.4628 |
| **User4** | **S → C** | 11.739 | 6.0776 | 2.1394 | 10.878 | 23.664 | 0.45968 | 1.8366 | 11.903 | 0.21248 | 2.3654 |
| | **C → S** | 11.743 | 6.0613 | 2.1420 | 10.881 | 23.628 | 0.46050 | 1.8448 | 11.908 | 0.21264 | 2.3657 |
| **User5** | **S → C** | 15.922 | 5.3797 | 2.9635 | 14.705 | 24.385 | 0.60304 | 2.9936 | 16.210 | 0.20524 | 2.6675 |
| | **C → S** | 15.727 | 5.6207 | 2.8342 | 14.556 | 25.944 | 0.56108 | 2.8141 | 15.986 | 0.19921 | 2.6586 |
| **User6** | **S → C** | 14.133 | 4.9851 | 2.6632 | 13.058 | 23.591 | 0.55352 | 3.2116 | 14.424 | 0.21018 | 2.5480 |
| | **C → S** | 13.997 | 5.5342 | 2.4946 | 12.976 | 26.014 | 0.49883 | 2.6731 | 14.233 | 0.20074 | 2.5438 |

**Table 4. A-D test results**

| | | Weibull | Normal | Gamma | Extreme Value | Lognormal |
|---|---|---|---|---|---|---|
| **User1** | **S → C** | √ | √ | √ | √ | √ |
| | **C → S** | √ | √ | √ | √ | √ |
| **User2** | **S → C** | √ | √ | X | X | X |
| | **C → S** | √ | √ | X | X | X |
| **User3** | **S → C** | √ | √ | √ | X | √ |
| | **C → S** | √ | √ | √ | X | √ |
| **User4** | **S → C** | √ | √ | X | X | X |
| | **C → S** | √ | √ | X | X | X |
| **User5** | **S → C** | √ | √ | √ | √ | √ |
| | **C → S** | √ | √ | √ | √ | √ |
| **User6** | **S → C** | √ | √ | √ | X | √ |
| | **C → S** | √ | √ | √ | X | √ |

*Digital Object Identifier: 10.4108/ICST.IMMERSCOM2009.6455*
*http://dx.doi.org/10.4108/ICST.IMMERSCOM2009.6455*