

A Survey of Transport Protocols for Haptic Applications

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Abstract—The term Haptic refers to the sense of touch. The feeling has the ability to increase the sense of reality, to excite the user and improve the quality of experience. To carry out this sense through the Internet was, until recently, impracticable due to processing inefficiencies and/or protocol performance in capabilities, such as throughput and jitter constraints. This paper describes a Haptic system architecture. Moreover it presents a survey of transport protocols for haptic applications. It also performs a classification of related protocol capabilities and outlines the flow requirements that should be met by protocols designed to carry such data.

Keywords- *Tele-Haptics, collaborative Haptics, tactile feedback, Transport Protocols, Teleoperation.*

I. INTRODUCTION

In the last decade much interest has been given to Haptic applications. This interest is due to the high Quality of Experience (QoE), that a user perceives when he uses a Haptic service [1]. Until recently, Haptic applications were limited in number and found only in High-Speed networks due to high processing and transmission requirements of Haptic data. Personal computer processing capabilities and LAN network speed improvements, in conjunction to the growth of WWW and development of Internet applications, made it feasible to develop applications using a special Internet flow-branch called Haptic Internet and operate applications known as tele-Haptics.

Tele-Haptics can be used in many areas of our life, like education [2], video games [3], military operations [4], tele-surgery [5] and video enhancement [6]. Moreover, Haptics can aid people with disabilities [7], transform virtual reality to augmented reality [8] and enhance communication between people [9].

Focusing on transmission protocol requirements, studies [10, 11] have shown that Haptic applications are sensitive to network conditions such as network delay, jitter, packet loss, out-of-order packet delivery and increased network congestion. Many methods have been investigated to optimize tele-Haptics transmission. Some of these techniques are multiplexing [12], perception-based data reduction [13], prediction-based data reduction [14], network prediction or network resource allocation [15], Haptic visual aid decorators [16], wave

variables [17] and application-centric data transmission protocols.

The protocols that specialize in Haptic data transmission are SCTP [18], SMOOTHED-SCTP [19], IRTP [20], RTNP [21], ETP [22], and RTP/I [23]. Some of these protocols, such as IRTP and RTNP were not created specifically for Haptic applications but for other Robotic tele-operations and vision, carried out through IP networks. Both Haptic and robotic applications present the same requirements for data transmission, so that these protocols can be applied to both applications.

The rest of this paper is organized as follows. Section II presents a Haptic system's high level architecture. Section III, analyzes novel internet architectures in regard to Haptic applications. In section IV QoS for Haptic data transmission and data flow requirements are described. Section V gives the related work of Haptic transport protocols and, while section VI describes the qualitative features of Haptic transport protocols. Finally, section VII identifies future research directions.

II. HAPTIC SYSTEM ARCHITECTURE

A typical Haptic System (HS) proposed by authors is comprised of the following structural parts as depicted at Figure 1.

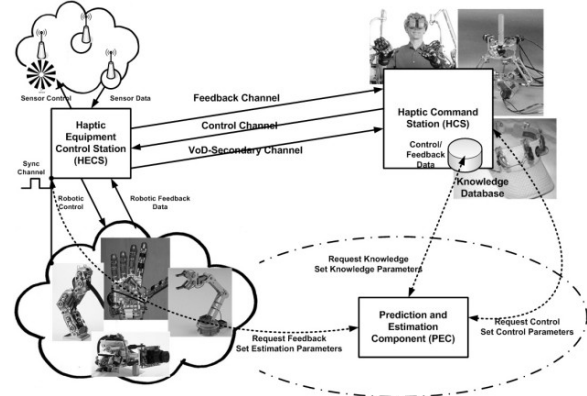


Figure 1. Proposed Haptic system and equipment high level architectural design following Realtime Control Systems (RCS) design [24, 25], close to RCS-3 architecture [26].

1. Haptic Command Station (HCS): This is the main control station of the HS. It contains three separate communication channels. Those are:
 - a. **Control channel**, which carries command queries to the Haptic equipment. Control data shall be encapsulated by an appropriate Control transmission protocol. It covers sensitive operations of robotic arms, devices of sense or touch receiving data that also perform sense or touch sensitive and delicate operations.
 - b. **Feedback channel**, which carries response queries to commands back to HCS (response info data and/or sensor data). Response data are both response sensor data of delicate sense operations provided by touch capable devices and/or supplementary sense information acquired by receive sense only equipment or real-time sensor equipment. Periodically received data of large update periods or additional but of no real-time importance sensor data provided by external sensor equipment must be maintained by a separate secondary channel
 - c. **Secondary channel**, carries regional, periodically updated or supplementary for the HCS system, but important for the HCS operator, sensor information. Such information is usually audio or video information from Haptic equipment to the HCS (also called VoD channel), or static sensor metric data (temperature, humidity, pressure, wind speed, precipitation etc).

The HCS also includes a knowledge database for the storage of historical information. Such information could become handy for future use by the Prediction and Estimation Component (PEC)[14, 27]. This PEC component shall either be part of the HCS station or incorporated at a separate management station. Its main functionality is to perform prediction algorithms on Haptic HCS system historical database records in order to generate behavioral responses for each application incidents accordingly. Appliance of data mining algorithms for statistical model building are also considered to be applicable.

2. Haptic Equipment Control Station (HECS): It is responsible for managing and monitoring all Haptic hardware equipment and also monitoring and receiving feedback activity from all peripheral sensors that are included in the Haptic system [28].
3. Prediction and Estimation Component (PEC): As mentioned to its functionality previously, PEC is either part of the HCS system or is maintained in a separate system and manages the HCS knowledge database. Its purpose is to monitor the Haptic system commands and provide useful predictions of HCS commands based on feedback data. Such a component shall utilize complicated data mining and estimation algorithms [27]. Its incorporation to the proposed Haptic system and clarification of its requirements and capabilities for

certain Haptic system use cases is set as a future work. That signifies the dashed line notation. Placement of the knowledge database either in the HCS or PEC system, focusing on improving Haptic system performance, is also set as a future work.

III. NOVEL INTERNET ARCHITECTURES IN REGARDS TO HAPTIC APPLICATIONS

The growth of www forced scientific community to come up with novel Internet architectures. Some of these architectures are the IPv6 and the “Internet of Things”[29]. Haptics can be applied to these architectures and benefit from their use.

A. Benefits from Using IPv6 for Haptic Data Transmission

Enforcement of the new Internet protocol IPv6 can improve the transmission of Haptic Data [30]. All clues indicate that IPv6 and QoS will play a major role in tomorrow’s communications. All ISP will have to implement the differentiated QoS in their routers and support IPv6.

1. IPv6 header contains an 8-bit **Traffic Class field**. With the help of this octet, Prioritization in data packets can be enforced. This prioritization can help differentiated QoS to be implemented. Haptic data should have higher priority from other multimedia. This necessity derives from the fact that Haptics are real-time data very sensitive to delay, jitter and update rate.
2. A field of the IPv6 header that also enhances the real time flow and the management of the QoS [31] is the **Flow Label**. It is a 20 bit field that informs the router in which flow does the packet belongs to and what QoS has to be enforced to. The concept of flows has already been met in haptic and real time protocols as SCTP, S-SCTP, RTP and is known as stream. The help of the flow-stream reduces processing time at the routers, helps packets to travel at the same path and keeps packets at the correct order. Moreover it helps protocols to enforce differential updates, a method that has been met in protocols as [18, 19].
3. Another characteristic of the IPv6 is the explicit support of **anycast**. This feature has already been met in some extensions of IPv4 but it is explicitly supported in IPv6. With the help of anycast transmission a packet can be send to a group of nodes of which the nearest one is automatically selected. Anycast minimizes the number of hops and the latency of a packet to reach its destination.
4. The **Multicast** transmission is also supported in IPv6 with better bandwidth efficiency than in IPv4. It ensures that all routers support multicasting and offers much larger multicast address space. Haptics can be applied in scalable architectures with multiple users that collaborate with each other. The need of use of multicast transmission is undoubted. In a large –scale virtual environment multicast group members can be

added or removed dynamically. Specific events as new members log in –log out, object acquisition and spam messages should have the ability to be sent to all the participants simultaneously.

5. **Security and privacy** are factors that are being reinforced in IPv6. Haptics could be applied in critical operations like military use and tele-surgery. It is obvious that a crack in the security of a tele-haptic system can cause problems that threaten human life.

B. The Role of Haptics in the “Internet of Things” Architecture

It is well known that Internet use is growing exponentially. Apart from the growth of usage, Internet is changing shape, type and services. Few years ago the meaning of “web 2” came in sight. The concept of “web 2” wants the Internet to be a user-centric platform for information sharing. The social media, blogs, wikis and video sharing are in their pick.

New ideas as the “Internet of Things” and the “web squared” [32] are now gaining attention. “Internet of Things” semantically means “a world-wide network of interconnected object uniquely addressable, based on standard communication protocols” [33]. The word “object” may refer to all things of our ordinary life such as vehicles, food packages, paper documents, clothes, furniture, etc. “Uniquely addressable” can be done with the help of the Radio-Frequency IDentification (RFID) and the IPv6, since IPv6 provides 128 bits for IP addressing. In the field of “interconnection” apart from RFID, tags, sensors, actuators, semantic technologies and smart phones can provide interconnection, cooperation and a new source of data for the new Internet which is called “web squared”. The “web squared” aims to integrate the “web 2” and the sensing technologies in order to provide a more enriched content to users.

Haptics can play a major role in the future Internet called “web squared”. Haptics are the key point of entry into a full sensory virtual reality, called “augment reality”. Haptics can immerse the user and provide the feeling of “being there”. If most objects of the real world addressed uniquely as the “Internet of Things” mentions and modeled- described with semantic technologies, then with the help of Haptics we can create an “augmented world” which will resemble our physical world. The gap between digital and physical world will be bridged.

The benefits from such an implementation would be breathtaking. Education, travelling, communications, logistics, robotics and many other areas will change rapidly and will obtain another meaning in our daily life. The “augmented world” will change our descendants’ lives as the Internet and the television changed ours and our antecessors’ lives.

IV. NETWORK TRAFFIC CHARACTERISTICS OF HAPTICS

The transmission of Haptic data has some unique characteristics that distinguish it from other transmitting multimedia like video and audio. Since Haptics refer to a human sense, it is quite difficult to infer the requirements for

transmitting Haptic data. A metric that has been used is the Mean Opinion Score (MOS) [34]. The time that is required to perform specific tasks [35] and the deviation of the Haptic device from a predetermined route [36] have also been used for establishing QoS parameters for Haptic transmission. The update rate in such applications should be 1 KHz [37, 38, 39].

Haptics require timely delivery of information. The Achilles’ heel of a Haptic system is the Packet Delay Variation (PDV), also known as jitter [40]. Studies [1, 41, 42, 43] have shown that the delay must be less than 50 ms, the jitter smaller than 2 ms and the packet loss less than 10%.

Comparatively speaking, Haptic systems are more sensitive to jitter, delay, and update rate and tolerant to data loss and bandwidth. According to Table I the refresh rate of the video data is much smaller than that of the Haptic data. The throughput of a Haptic System is smaller from a Video system and a little bit bigger than that of an audio System

TABLE I. QOS REQUIREMENTS

QOS	HAPTICS	VIDEO	AUDIO	GRAPHICS
JITTER (ms)	2	30	30	30
DELAY (ms)	50	400	150	100-300
THROUGHPUT (kbps)	512-1024	2500 - 5000	200	1200
DATA LOSS (%)	10	1	1	10
UPDATE RATE (Hz)	1000	30	8000	30

V. HAPTIC TRANSPORT AND APPLICATION LAYER PROTOCOLS

Quite enough protocols have been proposed to transfer Haptic data. Some of them were created for this purpose while others were developed for robot tele-operation [44].

S-SCTP [19]: Smoothed - Synchronous Collaboration Transport Protocol (s-SCTP). It derived from the SCTP [18] but differs in that it includes a buffer at the receiver’s side to reduce the unwanted effect of jitter.

IRTP [20]: Another protocol that applies to interactive applications is the Interactive Real-time Protocol (IRTP). It is connection oriented and is located at the transport layer. For its implementation it imitates the TCP for the transport of “crucial data” and the UDP for the transport of the “remaining data”.

ETP [22]: The Efficient Transport Protocol (ETP) is designed especially for Haptic applications. Its main target is to optimize the available bandwidth by trying to minimize the Inter Packet Gap (IPG) and the round trip time (RTT). The protocol that resembles ETP is the Bidirectional Transport Protocol (BTP) [45].

RTNP [21]: Real Time Network Protocol (RTNP). Its main drawback is that it can be implemented only in unix environments. Its main feature is that it uses priority for its packet.

RTP/I [23]: Real Time Application Level Protocol For Distributed Interactive Media (RTP/I). It also uses UDP for the

“unreliable data” and TCP for the “reliable data”. Its main drawback is that it has a big overhead of 28 bytes at every datagram in order to support a wide spectrum of applications.

ALPHAN [35]: Application Layer Protocol for Haptic Networking (ALPHAN). It operates on top of UDP and it can easily be customized with the help of an XML-based description file. It supports prioritization with the help of multiple buffers.

HMTP [46]: Hybrid Multicast Transport Protocol (HMTP). It derives from the combination of four protocols: Scalable Reliable Multicast (SRM) [47], Reliable Multicast Transport Protocol (RMTP) [48], Selective Reliable Transmission Protocol (SRTP) [49] and Synchronous collaboration transport protocol (SCTP).

Table II (Appendix) presents the qualitative features of all the above protocols

VI. QUALITATIVE FEATURES OF HAPTIC PROTOCOLS

In order to achieve so high update frequencies (1 kHz) with so little delay (60ms) and jitter (<10 ms), protocols should contain some qualitative features. Table II (Appendix) presents all the protocols and the qualitative features that they fulfill.

Reliability: Some data of the control and feedback channel should be sent reliably. The proposed mechanism that reduces feedback amount as much as possible is the Negative Acknowledgement (NACK) [50] and the Selective Acknowledgment (SACK)[51].

Minimum Overhead: Haptic protocols have to keep as minimum overhead as possible. Each byte of overhead sensibly reduces protocol efficiency [20].

Congestion Control [52,53, 54]: Congestion control can avoid long delay and jitter due to network overload. Algorithms that could be applied for the congestion control are the AIMD [55] and the RAP[56].

Flow control: A sequence number and a buffer, at the receiver’s side, and will help to set packages in the correct order. Furthermore, each packet should carry a timestamp. It allows more precise RTT estimation.

Bandwidth Estimation [57]: The protocol should reduce transfer rate if it detects network overload so as to avoid congestion. Methods for determining an appropriate sending rate of the transport protocol can be found in [58], [59], [60].

TCP Friendly capability: As tele-Haptics refer to the Internet, Haptic protocols should try to be TCP friendly [61, 62]. There should be a tradeoff between fair network resource allocation and bandwidth optimization so as transmission requirements to be met.

Buffer Optimization: Many protocols use buffers to reduce the unwanted effects of jitter and the out of order arrival of packets. The important drawback introduced by the buffer is that it increases the mean time of the delay.

VII. CONCLUSIONS AND FUTURE WORK

It is worth pointing out that the research area of Haptics protocols is fairly new and open to research and development. The QoS for transferring Haptic data is particularly demanding and challenging in order to achieve the maximum QoE. The protocols that are used are either still in an infant stage, or not specialized for that purpose. The paper describes the architecture of a Haptic System. It analyzes transmission characteristics and the flow requirements of Haptic data. It presents the protocols that are used for the transmission of Haptic data and analyzes the qualitative features that these protocols should fulfill. Table II summarizes all the above information.

The next step is to evaluate and compare the above protocols in a simulation environment. From the simulation it will be possible to derive accurate statistical and qualitative data that will allow in-depth evaluation of the reported protocols. Taking the above information in consideration it is possible to either suggest corrections to the relevant protocols or create a new haptic protocol. To evaluate the behavior of Haptic protocols, performance metrics should be attained. Measures of the performance of a Haptics transport protocol should rely on tangible attributes. That is, Throughput or Goodput at the receiver end, packet loss, network delay, and Packet Delay Variation also called as jitter

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APPENDIX

TABLE II. HAPTIC TRANSPORT PROTOCOL PROPERTIES

Properties	Protocols									
	UDP	TCP	IRTP	RTP/I	SCTP	S-SCTP	ETP	RTNP	ALPHAN	HMTP
LAYER	TRNSP	TRNSP	TRNSP	APP	TRNSP	TRNSP	TRNSP	NTW	APP	TRNSP
CONGESTION CONTROL	NO	Cwnd	Cwnd		ACK-NACK	ACK-NACK	RATE BASED		NO	NACK
SEQUENCE NUMBER	NO	YES	YES	YES	YES	YES	NO		YES	YES
TIMESTAMP	NO	YES	NO	YES	NO	YES	NO		YES	NO
BUFFERS	NO	YES	YES	PARTIAL	NO	YES	NO		YES	YES
CONNECTION ORIENTED	NO	YES	YES	PARTIAL	NO	NO	NO		NO	NO
RELIABLE	NO	YES	PARTIAL	PARTIAL	PARTIAL	PARTIAL	NO		PARTIAL	PARTIAL
PACKET HEADER (BYTES)	8	20	9	28					16	
No TYPE OF MESSAGES	1	1	2	4	2	2	1		3	2
BANDWIDTH OPTIMIZATION	NO	YES	YES	PARTIAL	NO	NO	YES		NO	NO
PRIORITIZATION	NO	NO	NO	YES	NO	NO	NO	YES	YES	NO
MULTI-PLATFORM	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES
TCP FRIENDLY	NO	YES	YES	PARTIAL	NO	NO	YES		NO	NO