A Framework for Haptic Interpersonal Communication

Marufa Yeasmin Mukta
Electrical and Computer Engineering
Queen's University
Kingston, Ontario, Canada
Email: m.mukta@queensu.ca

Hossam S. Hassanein
School of Computing
Queen's University
Kingston, Ontario, Canada
Email: hossam.hassanein@queensu.ca

***Abstract*—Haptic Interpersonal Communication (HIC), a significant application of the Tactile Internet (TI), has garnered attention in the scientific community due to the increasing demand for interactive experiences involving touch, particularly in response to global crises like Covid-19. HIC encompasses various interdisciplinary domains crucial for its optimal functionality. However, there has been a notable oversight in its network domain, where real-time immersion is vital. To address this gap, our study aims to redefine the conventional understanding of HIC and outline the necessary conditions. In this paper, we propose a novel architectural framework for HIC, utilizing key enabling technologies such as Fog computing and Software-Defined Networking (SDN) to facilitate authentic tactile interactions through high data rate Ultra-Reliable Low Latency Communication (URLLC).**

***Keywords*—Tactile Internet, Ultra Reliable Low Latency Communication (URLLC), Haptic Communication, Haptic Interpersonal Communication, H-H, 5G, Beyond 5G.**

I. Introduction

Haptic Interpersonal Communication (HIC) brings the vision of Tactile Internet into practicality with the advancement of network infrastructure and communication technologies. Tactile Internet, in its original definition, aims to enable real-time control of objects as it enables transmitting haptic experiences in an immersive manner over long distances via the Internet. Alternatively, the notion of HIC extends the vision of Affective Haptics to mediate the sense of touch (kinesthetic/tactile cues), ensuring real-time immersion in an end-to-end communication network [1]. Utilizing haptic feedback, this new interaction modality becomes useful to various applications under the HIC umbrella, including health care, social networking, remote education, and online gaming/entertainment.

The typical HIC system architecture illustrated in Fig. 1 incorporates, 1) a local user with an agent of a remote user in a local environment; 2) a communication network; and 3) a remote participant with an agent of a remote user in a remote environment. Within the scope of Tactile Internet, HIC envisions haptic data exchange alongside audio and video data transmission [1]. In this context, haptic technologies establish the remote/local agent in a local/remote environment. The agents (either a virtual avatar or physical robot) are expected to have the haptic ability to communicate with users, providing a stellar level of immersion via the TI.

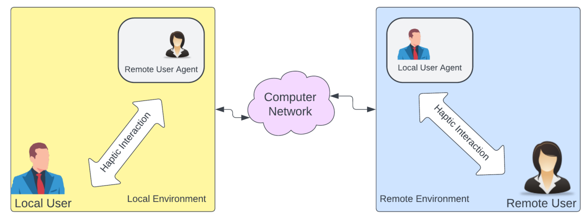

Fig. 1. Typical System Architecture of Haptic Interpersonal Communication adapted from [1].

II. Problem Statement

The HIC framework facilitates high-quality Human-Human (H-H) interaction, aligning with the 'Internet of Skill'. Introducing Haptic experience adds further complexity to a teleoperation system alongside delay and latency challenges. Mediated Social Touch [2] and Remote social touch [3] are closely related concepts but HIC differs in its emphasis on true immersiveness. The state-of-the-art HIC studies focus on haptic technologies in sensing and conveying affective haptic information and touch gestures. A successful HIC requires robust task and information sharing mechanisms to mitigate miscommunication and ensure optimal mutual understanding.

Haptic communication, as a bidirectional channel forming a global control loop, prioritizes services with strict latency and reliability constraints in data transmission, demanding symmetric resource allocation at both ends, i.e., command and the feedback signal [4]. This ensures minimal delay to maintain the perception of presence in an HIC setup and prevents disruptions/interruptions in feedback transmission. To transmit large amounts of data to represent real-time tactile sensation also demands high bandwidth. Moreover, the Quality of Service (QoS) management ensures specific QoS parameters such as jitters and packet loss to maintain the integrity of the feedback along with data prioritization and efficient resource allocation. Additionally, maintaining Quality of Experience (QoE) in HIC is crucial as it measures the perception of users and satisfaction in their interaction. A HIC system also requires further attention in maintaining safety and privacy, scalability, compatibility, interoperability, etc. [5].

To provide a real-time response in Tactile Internet applications like HIC, the communication network must support URLLC within limited bandwidth. Hence, upon considering the requirements of a HIC setup, in this paper, we propose to adopt recent technological advancements like fog computing, cloud networking, and Software-defined Networking (SDN) in a 5G framework to enhance HIC's practicality from its initial form (1 to 2.

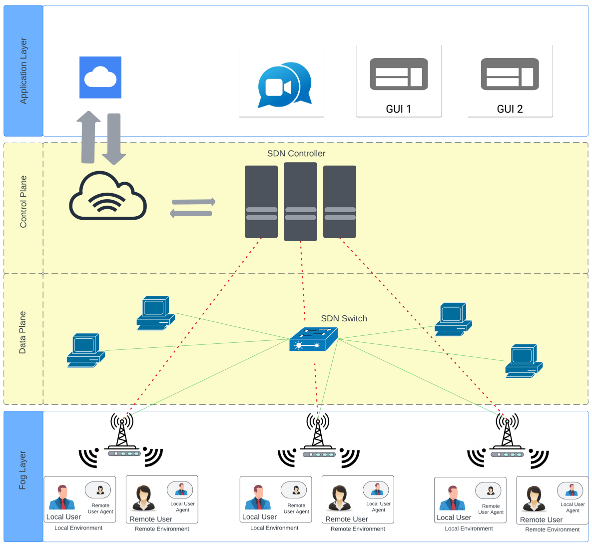

Fig. 2. Proposed framework for HIC

III. Proposed Framework for HIC

URLLC applications involve sporadic or intermittent data arrival traffic, often with a payload of very small size, e.g., 100 bits. Moreover, the end-to-end transmission data latency is restricted to 1 ms, and the probability of packet loss cannot go beyond 10^{-5} [6]. Considering the higher data rates in the matured version of 5G, 99% reliability is still a challenging field to provide career-grade access reliability. The proposed system architecture for HIC considers an SDN-based framework to reduce round-trip time by optimizing network paths and reducing latency. Through centralized control and programmability, SDN facilitates more efficient routing and prioritization of haptic data, leading to faster transmission and response times. Additionally, SDN enables dynamic adaptation to changing network conditions, further minimizing delays in remote haptic interactions.

A. Application Layer

The application layer protocols and services handle the exchange of data through different applications (e.g., video conferencing app, messaging app, etc.) across edge devices, catering to both remote and local users. Integrating SDN into the proposed framework centralizes network control, enabling more efficient management and optimization of network devices. This layer stands to gain significant performance improvement from SDN's capacity to dynamically adjust network configurations, prioritize traffic, and optimize routing paths based on specific application requirements.

B. Control Plane

The control plane is responsible for making high-level decisions about how data packets should be forwarded through the network. A programmable SDN controller acts as the brain of the network through a centralized control of intelligence. Essentially, the control plane decouples the network's control logic from the underlying physical infrastructure by running network control algorithms to compute optimal paths and traffic engineering policies based on the application requirements.

C. Data Plane

The data plane accounts for the actual forwarding of data packets based on the instructions received from the control plane. It consists of a variety of network devices such as SDN-enabled switches, routers, and access points, which execute the forwarding decision of the packets based on the flow rules installed by the SDN controller.

D. Fog Layer

The fog layer encompasses fog servers along with a variety of smart haptic-enabled devices, wearables, and more. These fog servers function as distributed compute nodes strategically deployed at the network's edge. They work alongside the centralized control and programmable management capabilities provided by the SDN controller. Furthermore, the infrastructure layer expands the data plane, accommodating both Local and Remote agents.

IV. Conclusion and Future Work

This research introduces Haptic Interpersonal Communication to enhance H-H interaction, addressing distinct challenges like ultra-low latency, high reliability, and high data rates. It presents an SDN-based HIC framework leveraging fog computing at the network edge to minimize delays in remote haptic interactions. Future endeavors will focus on implementing a multilevel cloud networking approach on top of the proposed framework, integrating traffic flow estimation for further enhancements.

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