The Potential of 6G Communication to Transform Healthcare in Remote Telesurgery

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***Abstract*—The healthcare sector routinely proves how humanity can push the limit of what is deemed technologically possible. This paper examines the benefits that 6G wireless communication may bring to healthcare infrastructure, focusing specifically on haptic telesurgery. To the best of our knowledge, this is the first experiment study that demonstrates the feasibility of haptic telesurgery in practice.**

Keywords—Haptic Telesurgery, 5G, 6G, Internet of Things, Wireless Communication, Force-Feedback, Haptics, Quality of Service, Smart Health

I. Introduction

The fifth-generation communication technology (5G) has opened a slew of new opportunities for technological development. The key enabling technologies within the 5G space include ultra-reliable low-latency connection (URLLC), communication services, enhanced mobile broadband (eMBB), massive machine-to-machine (M2M) and device-to-device (D2D) communication. To optimize advancement and innovation, cutting- edge tools must be continually supported by a robust digital infrastructure [1] [2] [3] [4] [5] [6]. In the context of the healthcare system, these major enabling technologies provide a vast number of new opportunities including the following: (1) provide Internet connectivity to Internet of medical things (IoMT) devices; (2) provide high-quality video calling for telemedicine and augmented reality (AR)/virtual reality (VR) for improved visualization in diagnosis and treatment; and (3) support drones and autonomous vehicles for both surveillance and emergency scenarios [3] [7].

However, 5G faces several limitations and obstacles in its pursuit of its goals. Various data-centric automated techniques are shown to exceed 5G's major performance standards [8]. For instance, haptics, telemedicine, and connected autonomous ambulances need larger packets with high reliability and data transfer rates. These applications contradict 5G's URLLC, and 5G has restricted coverage and mobility [4] [9]. Virtual and augmented reality technologies, such as holographic teleportation, will need microsecond latency and transmission rates of terabits per second (Tbps) [5] [10]. It would be implausible for 5G networks to handle such demands. In addition, the 106 devices/km^2 [11] 5G connection density may not be sufficient to meet the growing demands of the healthcare sector. Therefore, we want to know if 6G speeds have the potential to usher in a new era of technological advancement and expansion. In this paper, we will look at the various benefits that 6G communication may bring to healthcare infrastructure soon, with a particular focus on haptic telesurgery.

The following is how the rest of the paper is organized: Section II provides background information and a review of the related literature. Section III describes the research problem. Section IV discusses the methodology and data used in the simulation experiments. The results are presented and discussed in Section V. Finally, Section VI concludes our paper.

II. Background and Literature review

There have been quite a few theoretical studies on 6G. This technology will alter the course of our future and the healthcare sector in various ways. Table 1 shows some of the most recent representative research work that discusses the benefits 6G communication could bring to healthcare infrastructure and applications.

In general, 6G cellular technology is projected to deliver ultra-low latency and high-speed data transfer rate wireless services employing visible lights and THzEM sub-bands. The objective of 6G is to meet AI-based intelligent connection, holographic/haptic/satellite connectivity, and pervasive 3D connectivity [5] [10] [12] [13] [14], which will largely be beneficial to the healthcare industry.

III. Research problem

Given 6G's seemingly endless potential for usage in healthcare, we opted to focus our research on a single application: haptic telesurgery. Haptic telesurgery combines the typical process of robotically performed surgery with real-time haptic feedback to the doctor performing the surgery. We are talking about long-distance robotic surgery. Think about it, a patient in Seattle and the surgeon in Denver performing a complex operation on him where the surgeon receives tactile feedback from each movement he makes. Remote operations are not a new practice, successful long distance robotic operations date back to September of 2001 with the Lindbergh Operation [15]. However, while telesurgery may be a successful technology, it is still burdened by several factors. A clear disadvantage of robotic surgery devices is the lack of tactile feedback, large operation costs, training, and set-up [16]. Costs and extra training are disadvantages that can be soaked up, but there is no clear workaround for tactile feedback. Safe and efficient complex surgeries will only be possible through haptic technology which creates a virtual touch using force, motion, or

TABLE I. EXAMPLES OF FUTURE 6G-ENABLED TECHNOLOGICAL ADVANCEMENT AND EXPANSION IN HEALTHCARE

Author	Year	Technology	Analysis	Future scope
Mucchi et al. [12]	2020	6G; Internet of Bio-Nano-Things	• The number of chronic patients is growing. • 6G will make wireless healthcare a reality and enable Internet-of-Bio-Nano-Things. • The human body will be part of the "Net." • Clinical information would be constantly more accurate in a wireless healthcare world. • Network of updated patient information provides doctors and nurses with more decision-making tools.	• Working around the restricted energy consumption and computational abilities of body sensors • Further examination of molecular reactions and their role
Janjua et al. [13]	2020	6G	• Breakthroughs in communication are needed, especially as the number of disasters and pandemics increases. • Deploying IoMT and robots may be a solution to managing disasters. • These technologies require low latency which 6G can provide. • Autonomous ambulances may also be used to prevent aid workers from getting hurt in disasters. • Autonomous ambulances and medical assistance drones have many handovers and 6G can provide the needed vehicle-to-everything (V2X) communication technology.	• How is integration of these technologies into the healthcare system for real-time execution to be carried out?
Nayak et al. [14]	2021	6G	• 6G will have many use cases in healthcare. • Intelligent wearable devices, hospital-to-home services, and blood sample readers are all examples of 6G use cases.	• Methodologies of how 6G can be used to defend against attacks using AI, Quantum Machine Learning

vibration [17]. Tactile Internet is used to transfer the virtual touch to the robot and provide feedback. Tactile Internet requires a high speed of communication and ultra-low latency [17]. The transmission of signals over long distances is an unmistakable barrier for haptic telesurgery [18]. Long time delays limit feedback quality and can even pose risk to patients [18].

The purpose of this research is to examine the benefits that 6G can provide to haptic telesurgery, in particular, what benefits would 6G provide to haptic telesurgery that 5G cannot? Moreover, we strive to ensure that all challenges are treated equally. Even if we find evidence that supports previous question, are we being reasonable and taking the unknown into account? Finally, we will report the findings.

IV. EXPERIMENT METHODS

To analyze the latency differences (and other measurable variables) of 5G vs. 6G on haptic telesurgery, we constructed a network simulator. The network simulator is coded in Java and is closely based on the packet traversal model shown in the Fig 1.

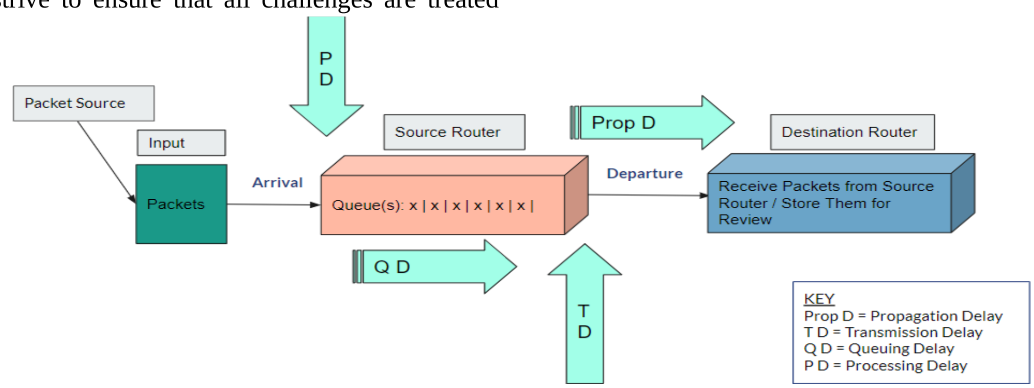

Fig. 1. Network simulator model.

Simulation output gives information on latency averages and maximums for background and haptic traffic. We can multiply streams to play with possible congestion or multiple simultaneous surgeries. Simulations run under first-come-firstserve (FCFS), round-robin [19], and strict priority scheduling [20] algorithms.

The data utilized to execute the simulation and model haptic video traffic are: packets from a Twitch Internet live stream, a sample network traffic data from the CESNET network, and simulated haptic packets arriving at rate 1000/s [21] and with an average packet size of 78 bytes [22].

V. Results and Discussion

Table II shows haptic video delay on average in terms of processing delay, queuing delay, propagation delay and transmission delay, along with total delay, among three different scheduling schemes. Processing delay is the time needed to process a packet header by a router. Queuing delay is the time spent by a packet waiting to be transmitted in queue. Transmission delay is the period to put the packet on the link. Propagation delay is the time for a packet to go from sender to receiver once on the link. A total delay per packet of 50ms is the maximum threshold for optimal and stable quality of service for tele-haptic interaction [21]. The Fig 1. model is the logic on which the simulation is based, and the following results are derived.

TABLE II. Average Haptic Delays in 5G networks at current 100Mb/s Verizon Upload Speed (5 minutes, 3 haptic streams:1 background stream)

	FIFO/FCFS	Round-Robin	Strict Priority
Processing Delay 1 Node	1.0ms	1.0ms	1.0ms
Queuing Delay 1 Node	3.702502ms	3.610483ms	0.492690ms
Propagation Delay 1 Node	12.491975ms	12.491975ms	12.491975ms
Transmission Delay 1 Node	0.065984ms	0.065984ms	0.065984ms
Total Average Delay 10 Nodes	60.176835ms	59.256645ms	28.078715ms

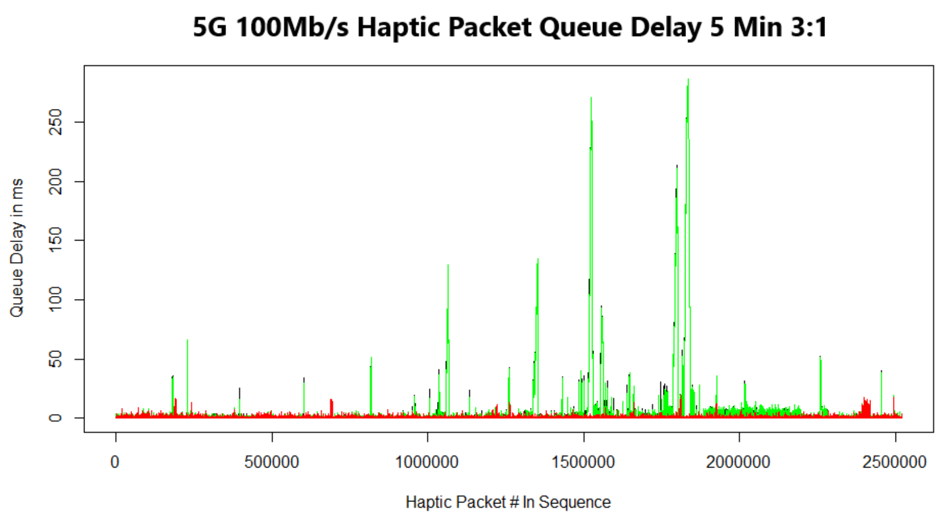

Fig. 2. 5G 100Mb/s 3:1 Haptic Packet Queue Delay (Black: FCFS, Green: Round Robin, Red: Priority Queue)

All packet tests are conducted with a simulated total distance of packet travel of 3,745km(2327mi) which is assumed to span 10 nodes. This represents the air travel distance between Seattle and Washington D.C. Additionally, tests use three haptic videos to a single background traffic stream. The average speeds in Table II appear promising as they are close to the threshold if not under. However, large delay spikes as seen in Fig. 2 prove to be an issue. At the current Verizon 5G upload maximum of 100Mb/s, FCFS and round-robin reach ~285ms peaks. Note that these values do not include processing, transmission, or propagation delay. Strict priority's highest queuing delay is ~5.6ms. With a long distance, even this smaller peak in delay becomes intolerable let alone when multiplied by a large number of nodes. Furthermore, latency may increase further if not all the transmission links are 5G based.

According to IMT-2020 standards, future 5G networks will be able to support upload speeds as fast as 10Gb/s and download speeds twice as fast [23]. However, it is difficult to achieve the maximum 5G speed in real networks with varying traffic dynamics, and hard to provide similar results. According to testing in 2021 T-Mobile, AT&T and Verizon only had averages of 30-40Mb/s on their enhanced mmWave 5G in the United States [24].

We conducted similar experiments in 6G networks. Theoretical download speeds for 6G are predicted to reach 1Tbps [9]. No information on upload speeds was locatable in the literature. We therefore model our first 6G test using the current 5G ratio of 1:100 where only one percent of theoretical upload speed is seen to be available for general use in ideal conditions.

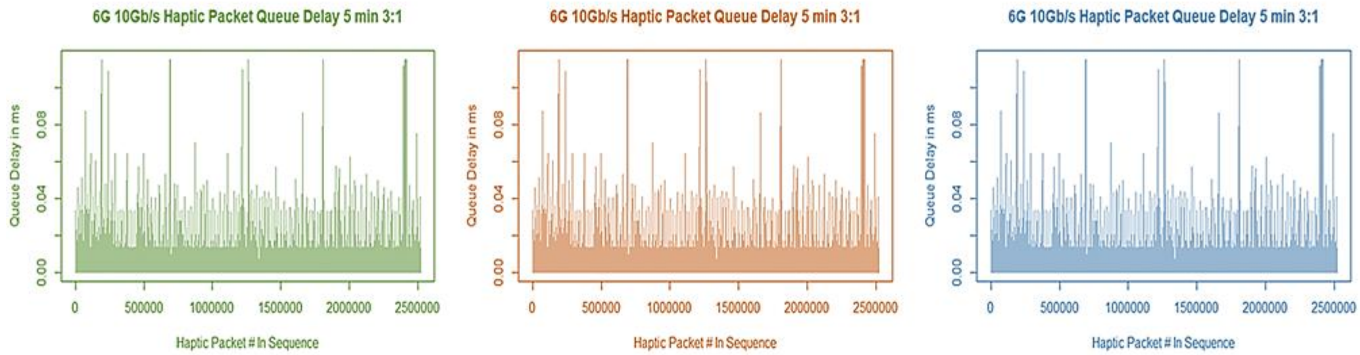

Fig. 3. 6G 10Gb/s 3:1 Haptic Packet Queue Delay (Lime: FCFS, Orange: Round-Robin ,Blue: Priority Queue)

As is indicated from Fig. 3 above, with 6G upload speeds that match the available upload speed ratio seen with current 5G, queuing delay is extremely small. All scheduling methods produced identical outputs. The average queueing delay for all three scheduling methods is .002137ms. When combined with the other delays and multiplied by 10 nodes, the threshold of 50ms is not surpassed Furthermore, the peaks fall within range of acceptable delay.

An additional test to show the queue delay at 1:10 utilization was also conducted. This test also shows all three scheduling methods produce identical outputs. The average queue delays for all three scheduling methods are .000212ms. These findings are even more promising in 6G supporting haptic telesurgery assuming more utilization of the maximum upload speed is available.

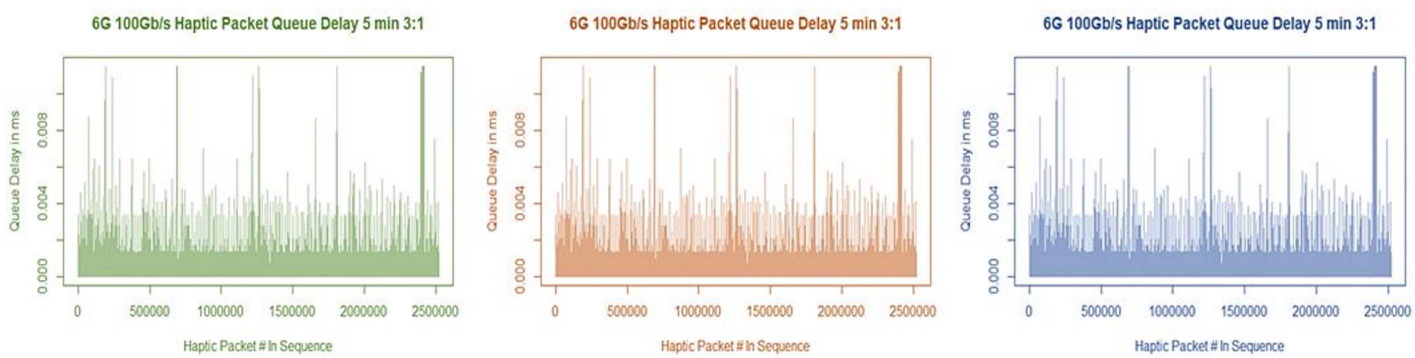

Fig. 4. 6G 100Gb/s 3:1 Haptic Packet Queue Delay, Estimate of 6G Upload Speed (Lime: FCFS, Orange: Round-Robin, Blue: Priority Queue)

VI. Conclusion

Our simulation results demonstrated that futuristic 6G technology provides better support compared to current 5G upload speeds for haptic surgery in practice due to extremely low latency. To the best of our knowledge, few simulation or experimental results have yet been published in the area. Our current tests examine the upload and transmission but omit the download when packets arrive. Future work will include the return of haptic feedback to the surgeon. In addition to testing network performance, an injection of malicious traffic may also be done to observe impacts on haptic telesurgery. Hacking of systems and malicious interference are a serious risk to haptic telesurgery [25] and may influence how results for future tests are interpreted.

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