**UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO**

**FACULTAD DE INGENIERÍA**

# A new telesurgery generation supported by 5G technology: benefits and future trends

**ARTÍCULO ACADÉMICO**

Que para obtener el título de

**Ingeniero en Sistemas Biomédicos**

**P R E S E N T A**

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**Ciudad Universitaria, Cd. Mx., 2022**

Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 200 (2022) 31–38

Procedia Computer Science

www.elsevier.com/locate/procedia

3rd International Conference on Industry 4.0 and Smart Manufacturing

# A new telesurgery generation supported by 5G technology: benefits and future trends

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**Abstract**

Telesurgery is a medical practice that has been developed for the last two decades. The idea is very simple, a highly trained surgeon performs a surgical intervention on a patient while being away from the operating room. The surgery execution is done through two principal equipment: a robotic one installed in the operating room and a remote station from which the surgeon controls the robot. The communication between both parties is established through a specialized internet connection.

The research and development of these remote surgery systems have been revolutionizing the medicine praxis due to its multiple benefits. During the last years, these systems have substantially improved many of their main limiting aspects, furthermore, the incorporation of 5G technology is a booster in telesurgery possibilities. Nonetheless, telesurgery benefits are not available for everyone because telesurgery requires high-cost equipment incorporation, specialized facilities and staff. This is the main reason for which health systems in developing countries dismiss its application.

As a result, this paper explains telesurgery with a brief historical review and future trends of this technology and also presents a value proposition that may facilitate telesurgery practice in remote medical units. Focusing on the implementations and benefits that 5G technology can provide to the development of telesurgery as a development opportunity medical praxis linked to the accelerated growth of high-speed networks in the connected world.



*Keywords:* Telesurgery; 5G; Robotic System.

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10.1016/j.procs.2022.01.202

## 1. Introduction

The interconnected world has been revolutionizing the development and monitoring of complex tasks, a clear example of this is found in the industry where any kind of activities are automated or manipulated to the distance. This is the beginning of process development controlled by teleoperations.

Teleoperation is a procedure that due to its nature and complexity involves human-machine interaction in multiple tasks accomplishments and whose application field have been increased in the last decades. The popularity of these systems is based on the minimization of operators' risk exposition. These systems have successfully accomplished their tasks in inhospitable environments such as space, nuclear plants, battlefields, underwater operations, among others [24]. Therefore telesurgery is a direct application of teleoperation in medicine, both providing unimaginable possibilities.

Telesurgery is a procedure where a specialized doctor performs surgery on a patient with the aid of a robotic system with the particularity that both the surgeon and the patient are in different locations. The telesurgery systems are given by two principal elements, shown in Figure 1: a) robotic surgery equipment, that in technical terms acts as a (slave), installed in a highly specialized operation room, and b) control console (master) operated by a trained surgeon that can be located hundreds or thousands of kilometres away from the OR and the patient.

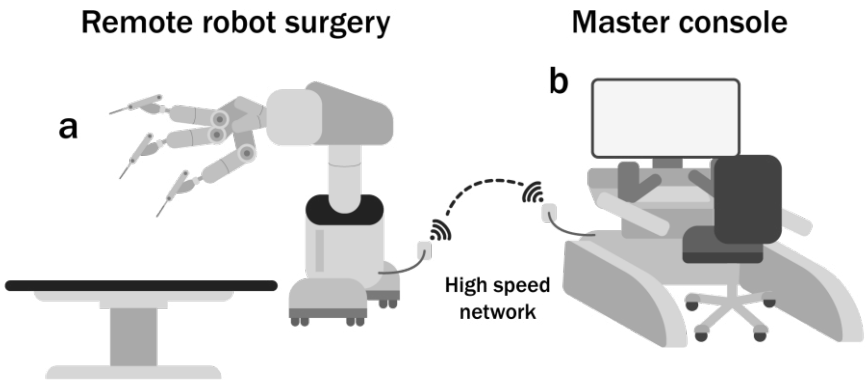


Fig. 1. Principal elements of a telesurgery system: (a) robotic surgery equipment; (b) control console. Both elements interconnected through a work network.

The communication between the principal elements must be fast and stable due to the procedures nature where there is no room for mistakes or perturbations that may put a patient's life in danger. This is the largest obstacle that telesurgery faces. In order to guarantee the security and reliability of the long-distance surgical procedures, it has been crucial to diminish the adverse effects related to the latency delay, the stability and the bandwidth of the interconnection network.

The end-to-end latency time in networks is the delay that appears from the moment that the remittent sends information till the reception of the receptor [6][7]. However, in the case of telesurgery, the information goes back and forth, leaving in form of instructions from the control console until it reaches the robotic equipment, coming back in an audible and visual way to the console monitor.

The human reaction to an audible, visual and sensorial stimulus is 100 ms, 40 ms and 1ms, respectively [10]. Taking into account these biological delays, it is possible to establish interactions that could be perceived as real-time responses by humans. Experienced surgeons determined that it is possible to perform complicated procedures through a robotic system with a latency delay lower than 150 ms [8]. For this reason, since the beginning of telesurgery, the use of high-speed optical fibre has been the predilect instrument for communication. Allowing to perform surgical procedures with relatively short latency delays.

## 2. Brief telesurgery review

In 1993 a long-distance laparoscopy was performed, the control console located in Pasadena, USA and the organic-material model placed in Milan, Italy. Three stations mediated the communication system, (one in New York, the second one in Pasadena and the last one in Milan) the interconnection was done using optical fibre, and two satellites (one located over the Atlantic and the other over the U.S.). The signal travelled 150,000 km and the distance in both directions among the centres was 14,000 km while the delay time reported during the procedure was 1.1 s [2].

The first transatlantic telesurgery was executed in 2001 with ZEUS robotic system to perform a cholecystectomy in a porcine model. The control console was placed in New York, USA and the surgery equipment in Strasbourg, France, being 14,000 km away from each other. Both sites were communicated with high-speed optical fibre with a bandwidth of 10 Mb/s, the general delay reported was 155 ms [1].

Asia also hosted a laparoscopic cholecystectomy in pork, Seoul Korea being the control site and Fukuoka, Japan the operation location. The direct distance between both places was 540 km, a bandwidth of 50 Mb/s through gigabit-class optic fibre with a response delay of 540 ms and an image delay of 871 ms. The procedure had a duration of 90 minutes, which is the average time that takes a traditional laparoscopic cholecystectomy [3].

During recent years, the evolution of mobile networks has augmented the speed and capacity of information transmission, causing the 4th industrial revolution, which is changing the paradigms of the way humanity lives, works, and communicates [9].

The 5G technology allows a more stable data transmission with a latency delay of 1-2 ms, that as compared to the 4G LTE technology has an improvement in velocity of 100 times the one achieved by 4G with 10 Gb/s and a simultaneous connectivity capacity considerably higher [11]. The impact of this technological revolution has reached telesurgery, promising solutions to networks limitations and granting the incorporation of new technologies like augmented reality and artificial intelligence.

In 2020 China performed 4 laparoscopic surgeries (left nephrectomy, partial hepatectomy, cholecystectomy, cystectomy) in porcine models. The first of their kind through a Wireless 5G connection at an approximate distance of 300 km in the cities of Qingdao and Anshun, using the MicroHand robotic system with UHD (4K) resolution in the recordings. It was reported a total delay of 264 ms and an operative total time of 2 hours, a similar time that conventional procedures would take [4].

The development of robotic surgery equipment and 5G technology have given space to the implementation of surgical procedures in the orthopaedic area, 12 telesurgeries have been performed in 7 women and 5 men with different spinal affections for treating 4 thoracolumbar fractures, 6 lumbar spondylolisthesis, and 2 lumbar stenoses. Six different hospitals participated in the procedures, being Beijing Jishuitan Hospital the control room and the hospitals Shandong Yantaishan Hospital, Zhejiang Jiaxing Second Hospital, Tianjin First Central Hospital, Hebei Zhangjiakou Second Hospital and Xinjiang Karamay Central Hospital the operation sites, with an average distance of 895 km. The surgeries were performed with the ‘TiRobot’ system communicating through a 5G wireless network.

Each one of them was a successful procedure and no problem regarding coactivity and response delay was reported [5].

## 3. Telesurgery challenges

Although telesurgery has had important breakthroughs during the last years, there are important problems that need to be solved to guarantee the safe practice of long-distance surgical procedures. Challenges are very punctual, from the latency time, reliability to the operation costs.

- Networks delays: Regarding the latency time, telesurgery require a reduction in network delays, for working near the real-time transmission <100 ms and giving the stakeholder the perception of it [12]. Given that mistakes could have a higher probability of occurrence if the surgeon is not aligned with the dynamics of the robotic equipment.

- Network reliability: It is a crucial aspect because connectivity must be available at every moment during the surgery, traditional networks commonly present Denial of Service (DoS) which can lead to fatal mistakes in the procedures and therefore compromise the life of the patient [13].

- Network security: Telesurgery needs to deepen in security protocols that protect the flux of information in adverse, uncontrolled, and hostile environments [14][15]. Confidential information and even patients' life could be compromised due to cybernetic attacks. Encryption innovations would need to be implemented for guaranteeing the safety of the procedures.

- High-cost implementation: Important challenges such as the communication costs, the initial investment and maintenance costs require special attention when a hospital is considering the acquisition of equipment for telesurgery. Commonly, special communication channels are used due to the high demand of network resources for executing the telesurgery procedures, resulting in high communication services costs [13][16]. Also, the cost of a telesurgery robotic system is around 0.5-1.5 MDD plus the installation, the consumables, and the maintenance costs, which makes it unaffordable in health systems in developing countries [17].

## 4. Telesurgery advantages

From the idea conception of executing long-distance surgical interventions in the decade of 1970, important telesurgery advantages and applications have been identified. For example:

- Extension of specialized medical attention coverage: Remote and difficult access places are a large obstacle for many people around the world, especially in developing countries where transportation routes are limited [22]. Making possible that patients could receive the service at their local hospitals rather than travelling long distances.

- Surgery execution in high-risk zones: Telesurgery has awakened a special interest within military entities due to the application possibility on the battlefield. In other words, it is convenient to perform surgical interventions in place, saving vital time in transfers to medical units [21].

- Surgery in inaccessible units: Telesurgery has gotten special interest for the Aerospatiale and naval industry because of the possibility of bringing specialized surgical care in space and on ships.[19]

- Accuracy increase: Last generation telesurgery equipment integrates advanced control and feedback systems capable of reducing tremors experienced by surgeons after long-lasting surgical operations. These systems are able to manage fine manipulations without complications.

- Minimally invasive procedure: Telesurgery is a minimally invasive procedure because of the tiny incisions made in comparison to the incisions made in traditional surgery techniques. As a result, the patient presents with lower blood loss and faster recovery [20][22].

- Ease of setting collaborations: Telesurgery has the ability to link experts of different parts of the world that evaluate in real-time the execution of highly complex procedures [13].

## 5. Future trends

The Inspiration 4 mission to be launched in 2021 stands as a genesis to civilian space travel with a 2 to 4-day flight in Earth's orbit providing room to new research developments in aeronautics, systems engineering, healthcare, physics, material science, among others. Inspiration 4 is a pivotal part of a unique generation of space travel, alongside the construction of Axiom Space, the first space station for tourists [18]. This opens up opportunities and challenges in medical care for civilian crews. It is important to note that although healthcare in space is widely controlled and has been developed since the decade 1970, these health robotic systems have been implemented successfully for trained crews, however, they have not been designed for civilian crews and will require adaptation processes for its development [19].

Telesurgery quality depends on surgeons' ability, the effectiveness of communication and the robotic system precision. All of them have been widely developed and innovations are appearing every year. Nevertheless, robotic systems could have a boost in innovation with the development of nanotechnology. Telesurgery might stop being executed by a 6 degree of freedom robot and be replaced by nanorobots that could perform the procedures. Although nanotech has deepened in other areas, nanorobots dedicated to telesurgery could change paradigms and enable new developments.

Telesurgery could lead to other important advances, not necessarily in the biomedical aspect but in specialized equipment maintenance, repairment or installation.

## 6. Proposal

Telesurgery supported by 5G technology has the ability to widen specialized surgical services coverage in a significant way. Nonetheless, there are places in the world where telesurgery is not easy to access. Mexico, for example, is a developing country with 48.8% of its population living below the poverty line [23]. It counts with a mostly government-funded public health system, which in theory every citizen has access to. Nevertheless, high speciality medical attention is available in large cities. This represents a serious obstacle in transferring patients from distant rural areas or cities that require specialized surgical interventions.

As a result, it is proposed the conceptual design of a mobile unit for telesurgery that includes an equipped surgical unit with telesurgery systems inside a tractor-trailer (18 wheels).

The system is designed to have a complete and functional surgery room inside the mobile unity that contains robotic surgical equipment being able to communicate through a 5G wireless network with the control console from which a specialized surgeon will perform long-distance surgical interventions, see Figure 2.

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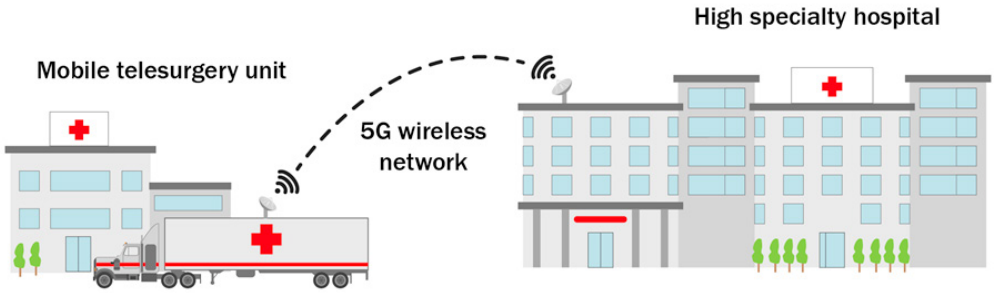


Fig. 2. Schematic representation of the interconnection between the mobile telesurgery unit and a high specialty hospital through 5G wireless network.

- Diagnosis and request: Once a patient has been diagnosed to be a candidate for a high speciality surgical intervention, he or she will be directed to the specialist through teleconsultation. The specialist doctor will be the one who approves and requests surgery in the nearest medical unit.

- Management for planning: With the objective of optimizing resources, the requests will be carefully reviewed for planning a strategic stay that fulfils the needs of nearby patients from an optimal location.

- Technical characteristics for a mobile telesurgery unit: It must include a completely instrumented surgery room, a preparation room for patients, a sterilization area, a medical staff station and a medicine stock, as we see in Figure 3. Also an uninterrupted electrical supply, air-conditioning system for medical units and surgical room, a supply of medicinal gases and potable water supply.

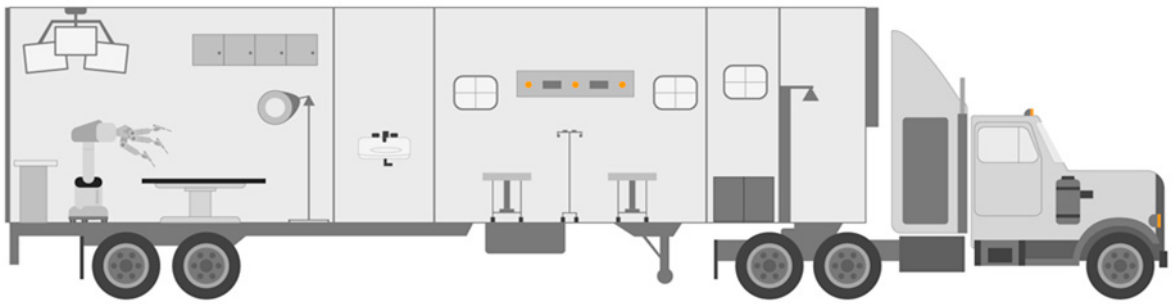

Fig. 3. Scheme of surgical mobile unit.

- Connectivity: A satellite fifth-generation wireless connectivity is vital as well as network safety for preventing cybernetic attacks that could compromise patients' privacy and even their lives during surgical procedures. This is why network security must be established or hired through a security protocol.

- Staff on board: In order to guarantee the right functioning of the mobile unit, a qualified medical team (a surgeon, two nurses and a biomedical engineer) needs to be on board the unit for attending to every need and emergency that could appear inside the unit. This with the objective to protect the patient's integrity.

Mobile surgical unit, as described above, is a conceptual proposal that contemplates in a general aspect, the essential requirements for its operation. Three major challenges have been identified in the formal design of the unit: the electrical installation for the fulfilment of special requirements of medical equipment, the air conditioning

system with special elements of filtering, establishing positive and negative pressures in determined areas, and the equipment distribution for telesurgery logistics, everything needs to be in place inside of the unit for its timely use.

## 7. Conclusions

Telesurgery has gained popularity all around the world in recent years as a result of the 5G technology incorporation that has solved some of the main limitations for its implementation. Nowadays the world is facing a technological application that in some years will be revolutionizing medical practice. Nonetheless, it is important to recognize that not everything is done and that it is vital to seek a technological vanguard.

It is important to mention that many people around the globe lack adequate medical attention services, in a high degree because of the complex task of transferring patients from hard access and long-distance places where they reside to large cities. Most of the time transport routes are insecure, limited and expensive. In this particular case, the proposed telesurgery mobile unit fulfils the latent need of enabling the access of specialized health services to everyone.

## References

[1] Marescaux J., Leroy J., Gagner M., Rubino F., Mutter D., Vix M., Butner S., & Smit M. (2001). "Transatlantic robot-assisted telesurgery ATM technology now enables operations to be performed over huge distances." NATURE **413**: 379-380.

[2] Rovetta A., Sala R., Cosmi F., Weri X., Sabbadini D., Milanesi S., & Togno A. (1993). "The first experiment in the world of robotic telesurgery for laparoscopy cawed out by means of satellites networks and optical fibres networks on 7th july 1993". IEEE Xplore 51-56.

[3] Arata J., Takahashi H., Pitakwatchara P., Warisawa S., Konishi K., Tanoue K., Ieiri S., Shimizu S., Nakashima N., Okamura K., Soo Kim Y., Min Kim S., Hahm J., Hashizume M., & Mitsuishi M. (2006). "A remote surgery experiment between Japan-Korea using the minimally invasive surgical system." IEEE International Conference on Robotics and Automation Orlando, Florida. 257-262.

[4] Zheng J., Wang Y., Zhang J., Guo W., Yang X., Luo L., Jiao W., Hu X., Yu Z., Wang C., Zhu L., Yang Z., Zhang M., Xie F., Jia Y., Li B., Li Z., Dong Q., & Niu H. (2020). "5G ultra-remote robot-assisted laparoscopic surgery in China." Springer Surgical Endoscopy **34**: 5172–5180.

[5] Wei T., Mingxing F., Cheng Z., Yajun L., Da H. & Qi Z. (2020). "Telerobotic Spinal Surgery Based on 5G Network: The First 12 Cases." Neurospine. **17(1)**:114-120.

[6] Bauknecht U. & Enderle T. (2020). "An Investigation on Core Network Latency." 2020 30th International Telecommunication Networks and Applications Conference (ITNAC).

[7] Li J., Chen L., & Chen J. (2021). "Enabling technologies for low-latency service migration in 5G transport networks [Invited]." Journal of Optical Communications and networking.**13(2)**: 200-210.

[8] Perez M., Quiaios F., Andrivon P., Husson D., Dufaut M., Felblinger J., & Hubert J. (2007). "Paradigms and experimental set-up for the determination of the acceptable delay in Telesurgery." Proceedings of the 29th Annual International Conference of the IEEE EMBS, Cité Internationale, Lyon, France.

[9] Hyoungju J., Sunho P., Jeongho Y., Younsun K., Juho L., & Byonghyo S. (2018). "Ultra-Reliable and Low-Latency Communications in 5G Downlink: Physical Layer Aspects." IEEE Wireless Communications. 124-130.

[10] Miao Y., Jiang Y., Peng L., Hossain M., & Muhammad G. (2018). "Telesurgery Robot Based on 5G Tactile Internet. SPRINGER Mobile Networks and Applications." **23(6)**: 1645-1654.

[11] Lacy A., Bravo1 R., Otero-Piñeiro A., Pena R., De Lacy F., Menchaca R., & Balibrea J. (2019) "5G-assisted telementored surgery. Wiley Online Library." **106**:1576–1579.

[12] Wirz R., Torres L., Swaney P., Gilbert H., Alterovitz R., Webster R., Weaver K., Russell P. (2015). "An experimental feasibility study on robotic endonasal telesurgery." Neurosurgery. **76:** 479–484.

[13] Rajesh G., Sudeep T., Sudhanshu T., & Neeraj K. (2019). "Tactile-Internet-Based Telesurgery System for Healthcare 4.0: An Architecture, Research Challenges, and Future Directions." IEEE Network.

[14] Tozal M., Wang Y, Al-Shaer E., Sarac K., Thuraisingham B., & Chu B. (2013). "Adaptive Information Coding for Secure and Reliable Wireless Telesurgery Communications." Springer Mobile Netw. **18**: 697–711

[15] Sohail I., Shahzad F., Khuram S., Asad Waqar M., Mian H., & Osman H. (2019). "SecureSurgiNET: A framework for ensuring security in telesurgery." International Journal of Distributed Sensor Networks.

[16] Cazac C. & Rad G. (2014). “Telesurgery – an efficient interdisciplinary approach used to improve the health care system.” Journal of Medicine and Life. **7(3)**: 137–141.
[17] Shi-Bo X., & Quing-Sheng L. (2021). “Development status of telesurgery robotic system. Chinese Journal of Traumatology.” (article in press).
[18] Inspiration4 (n.a.) “The First All-Civilian Mission to Space.” https://inspiration4.com/
[19] Haidegger, T., Sandor, J., & Benyo, Z. (2011). “Surgery in space: the future of robotic telesurgery. Surgical Endoscopy.” **25(3)**: 681–690.
[20] Boabang, F., Glitho, R., Elbiaze, H., Belqami, F., & Alfandi, O. (2020) “A Framework for Predicting Haptic Feedback in Needle Insertion in 5G Remote Robotic Surgery.” IEEE 17th Annual Consumer Communications & Networking Conference (CCNC).
[21] Richard M.Satava (1995) “Virtual reality and telepresence for military medicine. Computers in Biology and Medicine.” **25**: 229-236.
[22] Rayman, R., Primak, S., Eagleson, R. (2009). “Effects of Network Delay on Training for Telesurgery.” IEEE 1st International Conference on Wireless Communication, Vehicular Technology, Information Theory and Aerospace & Electronic Systems Technology.
[23] CONEVAL. Mexico (2018).
[24] Cui, J., Tosunoglu, S., Roberts, R., Moore, C., & Repperger, D. (2003). “A review of teleoperation system control”. Florida Conference on Recent Advances in Robotics, FCRAR, Boca Raton, Florida, May 8-9, 2003.