5G Technology in Remote Surgery (Telesurgery)

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***Abstract*—Remote surgery refers to performing medical operations from a distant location using connected systems that allows surgeons to perform operations on patients who are located far away. ,This is made possible using robotic systems and communication networks that transfer data in real time. In recent years, 5G technology has become an important enabler for such applications due to its ability to provide fast, stable, and low-delay communication.**

This study examines how important features of 5G, including low delay, stable connectivity, and fast data transfer, support surgical systems. It explains the role of important technologies such as low-latency communication, edge computing, and network slicing in maintaining real-time interaction between the surgeon and the patient.

The paper also highlights the advantages of telesurgery, such as better access to expert doctors, reduced travel, and faster treatment in emergencies. At the same time, it discusses challenges like high cost, data security risks, and the need for strong network infrastructure. Overall, the study shows that 5G has strong potential to improve remote surgical systems and make advanced healthcare more accessible

I. INTRODUCTION

In recent times, healthcare has changed rapidly with the adoption of new digital technologies. One of the most important developments in this area is the introduction of 5G communication technology. As the demand for faster and more reliable communication increases, especially in critical sectors like healthcare, traditional networks such as 3G and 4G are no longer sufficient to meet modern requirements.

5G provides faster communication, reduced delay, and the ability to connect many devices at the same time.These features make it highly suitable for healthcare applications where real-time data transmission is crucial. For example, in emergency situations, doctors need instant access to patient data, and any delay in communication can affect decision-making.

One important use of 5G in healthcare is telemedicine, where patients can consult doctors remotely using video calls and digital platforms. With 5G, the quality of communication improves significantly, making remote diagnosis more accurate and effective. Another important application is remote surgery, where surgeons can operate on patients from a different location using robotic systems. This is only possible with ultra-low latency, which ensures that there is no delay between the surgeon's actions and the robot's response.

Telesurgery allows a doctor to carry out operations from a different location using connected robotic systems and advanced communication networks. This approach is particularly useful in situations where access to skilled surgeons is limited, especially in rural or remote regions.

Older networks like 3G and 4Gare not suitable for such real-time operations of supporting remote surgery effectively due to high latency and unstable connectivity. Even a small delay in signal transmission can affect the accuracy of surgical movements, making the procedure risky.

With the introduction of 5G technology, these limitations can be significantly reduced. 5G provides ultra-fast communication, minimal delay, and highly reliable connections, making it

suitable for real-time medical applications. This has opened new possibilities for performing surgeries remotely with high precision and safety.

understanding of how 5G technology is transforming healthcare systems and what role it will play in the future of medical services.

II. LITERATURE REVIEW

The application of Remote surgery, also known as telesurgery, has evolved significantly with the advancement of communication technologies and robotic systems. Early developments in telesurgery relied on wired communication networks, which often suffered from high latency, limited bandwidth, and instability, restricting real-time surgical control. The integration of 5G technology has addressed many of these limitations, making telesurgery more practical and efficient.

Several studies highlight that telesurgery involves the use of robotic systems controlled remotely by surgeons through communication networks. According to recent research, telesurgery systems consist of a master console (surgeon side) and a slave robotic system (patient side) connected via high-speed networks

These systems enable surgeons to perform complex procedures from distant locations, improving access to specialized healthcare services.

A systematic literature review (2025) emphasizes that telesurgery has become a key area of innovation in modern healthcare, focusing on both technical aspects (latency, reliability) and non-technical aspects (ethics, safety, training)

The study identifies that achieving ultra-low latency and high reliability is essential for safe surgical operations, which was difficult with previous generation networksThe introduction of 5G networks has significantly improved telesurgery capabilities. 5G provides three key features:

Ultra-Reliable Low Latency Communication (URLLC)
Enhanced Mobile Broadband (eMBB)
Massive Machine-Type Communication (mMTC)

These features enable real-time transmission of high-definition video, haptic feedback, and control signals, which are critical for remote surgical procedures

Recent global reviews (2024–2026) show that 5G allows telesurgery over long distances (more than 3000–5000 km) with stable and uninterrupted communication
Experimental studies demonstrated successful robotic surgeries such as laparoscopic procedures performed remotely using 5G-enabled systems, confirming the feasibility of long-distance surgical operations.

Research also indicates that network latency is one of the most critical parameters in telesurgery. Even small delays can affect surgical precision and patient safety. 5G reduces latency to milliseconds level, enabling near real-time control of surgical robots

This advancement has made telesurgery more reliable compared to earlier wireless technologies.

Another important contribution in the literature is the integration of artificial intelligence (AI) and robotic systems with 5G networks. AI assists in image processing, decision support, and motion stabilization, improving surgical accuracy and reducing human error

The combination of AI, robotics, and 5G is considered a transformative approach in smart healthcare. However, several challenges are still identified in the literature. High implementation cost, requirement of specialized infrastructure, and cybersecurity risks are major barriers to large-scale adoption. Additionally, ethical concerns such as patient safety, legal responsibility, and data privacy remain important issues in telesurgery systems

Recent studies also emphasize that despite technological advancements, telesurgery is still not widely adopted in developing regions due to limited resources and lack of infrastructure

Researchers suggest that future work should focus on cost reduction, network optimization, and regulatory frameworks to make telesurgery accessible globally.

In conclusion, the literature indicates that 5G technology has played a crucial role in advancing telesurgery by providing low latency, high bandwidth, and reliable communication. While significant progress has been made, further research is needed to overcome challenges related to cost, security, and scalability to ensure widespread adoption of 5G-

enabled remote surgical systems.

III. PROBLEM STATEMENT AND OBJECTIVES

Problem Statement

The advancement of remote surgery (telesurgery) has created new possibilities for delivering specialized medical care across geographical boundaries. However, performing surgical procedures from a distant location requires extremely fast, reliable, and uninterrupted communication between the surgeon and the robotic system.

Existing communication technologies such as 3G and 4G networks are not capable of meeting these requirements due to higher latency, limited bandwidth, and inconsistent connectivity. Even a slight delay in signal transmission can result in inaccurate surgical movements, which may lead to serious risks for the patient.

In addition, remote surgery systems require the continuous transmission of high-definition video, real-time sensor data, and precise control signals. Traditional networks are unable to handle such high data demands efficiently, especially in critical situations.

There are also concerns related to data security, network reliability, and system integration, which further limit the adoption of telesurgery in real-world healthcare environments.

Therefore, the main problem is to develop a communication system that can provide ultra-low latency, high reliability, and secure data transmission to support safe and accurate remote surgical procedures. 5G technology is considered a potential solution to address these challenges and enable effective implementation of telesurgery.

IV. OBJECTIVES

The primary objective of this research is to study how 5G technology can be used to improve the performance and reliability of remote surgery systems.

Specific Objectives:

- To understand the concept of remote surgery (telesurgery)

This objective focuses on studying how remote surgical systems work and the role of communication networks in enabling such procedures.

- To analyze the limitations of existing communication technologies

This includes identifying the challenges of 3G and 4G networks, such as high latency and low reliability, in supporting real-time surgical

operations. To examine the role of 5G technology in remote surgery

This objective aims to understand how 5G features such as ultra-low latency, high data speed, and reliable connectivity improve telesurgery performance.

- To study key 5G technologies used in telesurgery

This includes analyzing technologies such as URLLC, edge computing, eMBB, and network slicing, and their contribution to real-time surgical communication.

- To identify the benefits of 5G-based remote surgery

This objective focuses on understanding how telesurgery improves access to healthcare, reduces delays, and enhances surgical precision.

- To analyze challenges and limitations of implementation

This includes studying issues such as infrastructure cost, data security risks, and the need for reliable network systems.

- To explore future scope of 5G in surgical applications

This involves examining how advancements in AI, robotics, and communication technologies can further improve remote surgery systems.

V. WORKING AND ROLE OF 5G-BASED REMOTE SURGERY

In a 5G-enabled telesurgery system, the surgeon operates from a remote console equipped with control devices. These controls are connected to robotic arms located near the patient. The surgeon's hand movements are translated into precise actions performed by the robotic system.

At the same time, high-definition video and sensor data are transmitted back to the surgeon in real time. This allows the surgeon to view the surgical area and make accurate decisions during the procedure.

The entire system depends on continuous and instant communication between the surgeon and the robotic system. Any delay or interruption can affect the outcome of the surgery. This is where 5G technology plays a critical role by ensuring smooth and real-time

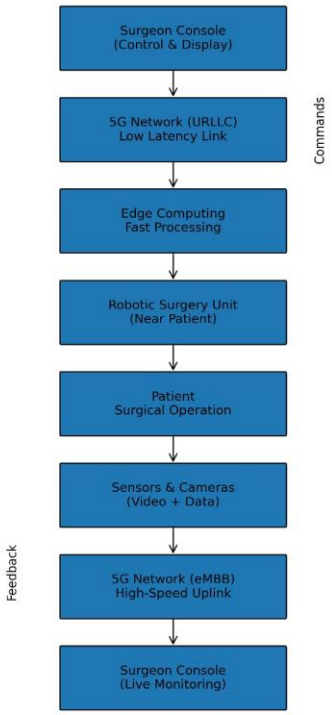
data exchange.

5.1Ultra-Reliable Low Latency Communication (URLLC)
URLLC ensures extremely low delay in communication, which is essential for real-time surgical control. It allows the robotic system to respond instantly to the surgeon's commands, improving accuracy and safety.

5.2 Edge Computing
Edge computing processes data closer to the patient instead of sending it to distant servers. This reduces response time and allows faster decision-making during surgery.

5.3 Enhanced Mobile Broadband (eMBB)
eMBB supports high-quality video transmission, enabling surgeons to view the surgical area in high resolution without interruptions.

5.4 Network Slicing
Network slicing provides a dedicated communication channel for surgical procedures, ensuring that there is no network congestion or interference during critical operations.



This diagram illustrates the flow of communication in a 5G-enabled telesurgery

system. The surgeon's commands are transmitted through a low-latency 5G network to the robotic surgical unit, while real-time video and sensor feedback are sent back to the surgeon for continuous monitoring.

VI. METHODOLOGY

The methodology adopted in this study is analytical and descriptive in nature, focusing on understanding how 5G technology can be effectively utilized to support remote surgery (telesurgery). The research does not involve physical implementation but is based on systematic analysis of existing technologies, research findings, and practical applications.

6.1 Research Approach
The study follows a structured approach to examine the role of 5G in enabling remote surgical procedures.

In the first stage, the basic concept of remote surgery is studied, including its working mechanism, system components, and communication requirements. This helps in identifying the critical factors necessary for performing surgeries from a distant location.

In the second stage, the limitations of existing communication technologies such as 3G and 4G are analyzed. Parameters like latency, bandwidth, and reliability are evaluated to understand why these technologies are not suitable for telesurgery.

The third stage focuses on the detailed study of 5G technology. Key features such as ultra-low latency, high data transmission speed, and massive connectivity are examined to understand how they overcome the limitations of previous networks.

6.2 Analysis of 5G Technologies in Telesurgery
This phase involves studying specific 5G technologies that directly support remote surgery. Technologies such as Ultra-Reliable Low Latency Communication (URLLC),

Enhanced Mobile Broadband (eMBB), edge computing, and network slicing are analyzed in

relation to their role in real-time surgical operations. Each technology is evaluated based on how it contributes to reducing delay, improving communication quality, and ensuring system reliability during surgical procedures.

6.3 System Workflow Analysis

A conceptual model of a 5G-enabled remote surgery system is considered to understand the flow of data between the surgeon and the patient. The process includes transmission of control signals from the surgeon, execution of actions by robotic systems, and real-time feedback through video and sensors.

This step helps in identifying the importance of continuous two-way communication and the role of 5G in maintaining synchronization between different components of the system.

6.4 Comparative Evaluation

A comparison is made between traditional communication technologies (3G/4G) and 5G based on key performance indicators such as latency, data speed, reliability, and device connectivity.

This comparison highlights the improvements offered by 5G and justifies its suitability for critical healthcare applications like remote surgery.

6.5 Identification of Challenges

The methodology also includes the analysis of challenges associated with the implementation of 5G in telesurgery. Factors such as high infrastructure cost, data security concerns, network reliability, and technical complexity are studied.

6.6 Scope of the Study

The study is limited to theoretical and analytical evaluation of 5G in remote surgery. It does not include practical experimentation or hardware development.

The focus is on understanding concepts, technologies, and system behavior rather than building a physical model.

VII. RESEARCH APPROACH

The research follows a systematic and experimental approach to study how 5G technology can improve the performance and reliability of remote surgery systems. The methodology combines theoretical study, simulation, and performance evaluation.

7.1. Problem Identification

The study begins by identifying key issues in existing telesurgery systems such as:

- High communication latency
- Network instability
- Limited real-time control
- Safety risks during remote operations

These limitations highlight the need for advanced communication technology like 5G.

7.2. Literature Analysis

A detailed review of existing research is conducted to understand:

- Evolution of telesurgery systems
- Role of communication networks (4G vs 5G)
- Current challenges and research gaps

This step helps in defining the research direction and objectives.

7.3. System Design Framework

A conceptual model of a 5G-enabled telesurgery system is developed, which includes:

- Surgeon console (control unit)
- Robotic surgical system (patient side)
- 5G communication network
- Data transmission modules (video, audio, haptic feedback)

7.4. Technology Integration

The research focuses on integrating key 5G features into the system:

- Ultra-low latency communication
- High-speed data transfer
- Reliable connectivity

Additional integration may include:

- AI-based assistance for precision
- IoT sensors for real-time monitoring

7.5. Simulation and Modeling

Simulation tools (such as MATLAB or Python) are used to:

- Model network performance
- Analyze latency and data transmission delay
- Evaluate system response under different conditions

7.6. Performance Evaluation

The system is evaluated using key parameters:

- Latency (delay in communication)
- Reliability (packet loss, connection stability)
- Accuracy of surgical movement
- Quality of real-time video transmission

7.7. Comparative Analysis

The performance of the proposed 5G-based system is compared with:

- Traditional wired systems
- 4G-based telesurgery systems

This helps to show improvements in efficiency and reliability.

7.8. Result Interpretation

The obtained results are analyzed to:

- Determine effectiveness of 5G in telesurgery
- Identify advantages over existing systems
- Highlight any limitations

7.9. Validation and Future Scope

The findings are validated with existing research studies.

Future improvements are suggested, such as:

- Enhancing cybersecurity
- Reducing implementation cost
- Expanding real-world deployment

VIII. ADVANTAGES

- Enables access to expert surgeons from any location
- Reduces travel time for both patients and doctors
- Improves emergency response in critical situations
- Provides high precision through robotic assistance
- Enhances collaboration between medical professionals

IX. CHALLENGES AND LIMITATIONS

Despite its advantages, remote surgery using 5G faces several challenges:

- High cost of robotic systems and infrastructure
- Dependence on stable and reliable network connectivity
- Risk of cyber-attacks and data breaches
- Requirement of skilled professionals to operate advanced systems
- Addressing these challenges is necessary for large-scale adoption.

X. FUTURE SCOPE

The future of remote surgery looks promising with the continuous advancement of 5G and related technologies. Integration with Artificial Intelligence can further improve surgical accuracy by assisting in decision-making. The use of advanced robotics and improved network infrastructure will make remote surgery more accessible and efficient.

In the coming years, 5G-enabled telesurgery may become a standard practice in healthcare, especially in regions where access to specialized medical services is limited.

XI.CONCLUSION

Remote surgery is one of the most significant applications of 5G technology in healthcare. By providing ultra-low latency, high reliability, and fast data transmission, 5G enables surgeons to perform complex procedures from distant locations with high precision.

Technologies such as URLLC, edge computing, eMBB, and network slicing play a crucial role in ensuring the success of telesurgery systems. These technologies work together to create a reliable and efficient communication environment required for critical medical operations.

Although there are challenges related to cost, security, and infrastructure, ongoing advancements are expected to address these issues. With proper implementation, 5G-based remote surgery has the potential to revolutionize healthcare by making high-

quality medical services accessible to people regardless of their location.

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