

6G internet of things networks for remote location surgery also a review on resource optimization strategies, challenges, and future directions

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ABSTRACT

Remote location surgery presents stringent requirements for wireless communication, particularly in terms of reliability, speed, and low latency. The emergence of sixth-generation (6G) wireless networks is expected to address these challenges effectively. With the rapid expansion of internet of things (IoT) applications in healthcare, maintaining real-time connectivity has become essential. Ensuring such performance in 6G-enabled IoT networks relies heavily on the implementation of advanced resource optimization techniques. Recent studies have focused on improving key performance metrics, including latency, reliability, energy efficiency, spectral efficiency, data rate, and bandwidth usage. Comprehensive reviews of these techniques reveal a growing emphasis on multi-objective optimization strategies to balance conflicting requirements. Research has also highlighted limitations in existing approaches, suggesting the need for further innovation, particularly for mission-critical applications like remote surgery. Within this context, 6G IoT systems have demonstrated the potential to maintain high data rates and stable throughput, both of which are essential for safe and responsive surgical operations conducted over long distances. These findings underscore the importance of continued development in resource management to fully enable remote healthcare delivery through advanced wireless technologies.

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1. INTRODUCTION

Internet of things (IoT) application scenarios have expanded in variety with the widespread commercial use of 5th generation (5G) mobile communications as per [1]. Network resource optimization is essential for successful mobile communication from second generation (2G) to fifth generation (5G). However, there are not enough resources available and wireless communications are getting close to Shannon constraints. The next generation (6G) communication system offers a broader reach than the 5G mobile communication network [2], enabling the realization of integrated satellite, the earth, the sky, and the ocean. It is necessary to implement novel resource optimization techniques in order to guarantee the quality of service (QoS) in 6G networks [3], [4]. The key technology in the 6G network is internet of things (IoT) [5]. The IoT integrates diverse networks and sensor devices to enable the connection of people, objects, and machinery at any time and location was discussed in [6]. Massive amounts of data have been generated by the expansion of IoT devices [7], yet the potential of data privacy breaches is rising. During the multi-user data connection process, several data security issues have come to light [8]. In addition, artificial intelligence

(AI)-enabled solutions are increasingly used to enhance resource management in 6G systems [9]. Three types of situations exist for protecting privacy: gathering, sharing, and using data. The IoTs' sensing nodes are extremely susceptible to enemy attacks in a data collection situation. The enemy can acquire or fabricate the legal identity using a number of methods, win the sensing node's trust, and then get the privacy information the sensing node has gathered.

The purpose of this paper is to explore more efficient techniques for 6G resource optimization for internet of things communication systems. First, we examined the effects of several variables on 6G IoT networks' communication performance. Next, there are six important metrics to look for in the enhanced communication performance of 6G technology: transmission rate, latency, bandwidth utilization, energy efficiency (EE), spectrum efficiency (SE), and transmission reliability.

Here, in this work, we are going to address the scope of remote location surgery as an application with 6G enabled IoT networks. Here, we will test the performance and advantages provided by 6G enabled IoT networks for resolving the challenges faced by RLS. The surgeons or patients who are present at remote locations and have no access for the resources of the operation or surgery can be achieved through a technique called remote location surgery which will be used to provide necessary treatment using IoT networks. IoT devices (*e.g.*, sensors, wearables) gather critical patient data such as vitals (heart rate, blood pressure, oxygen saturation) and environmental parameters (operating room conditions).

The problem with implementation of remote surgery is, the need for high data rates and throughput at a very high speeds, because the robots which involves here will works at a very high speed, so, the instructions of the doctor present at a remote location need to be transferred very fast such that no errors will takes place. Till 5G, networks provided data rates and throughput that was decent but lacks consistency means for longer durations. So, here these challenges will be resolved with the introduction of 6G communications, which typically having a higher data rates and throughput transfer availability, here, we've used Terahertz communication which lies in the Terahertz (100 to 10000 GHz) range of which actually supported by 6G networks for providing higher data rates. The data security will be handled by 6G algorithms like AES 128 which is considered to be more robust than the existing ones.

To ensure robust QoS in high-demand scenarios, adaptive and dynamic allocation methods are essential. Cyber Twin-based architectures provide a novel approach to managing these challenges by allowing real-time optimization of spectrum, computing, and storage resources in 6G environments [10]. Such frameworks highlight the importance of integrating advanced architectures with classical optimization for sustainable performance.

The resource optimization strategies of six distinct indicators in 5G and 6G IoT communication networks are proposed in section 2. The combined optimization strategy among the six indicators is examined in section 3. The difficulties of resource optimization are discussed in section 4, potential avenues for future research are presented in section 5, and the article's findings are presented in section 6.

2. METHOD

One of the main strategies in the 6G network is internet of things communication. Nonetheless, a number of issues, including limited wireless spectrum availability, sensor networks' high energy consumption, unreliable connections, and lengthy transmission latency, must be taken care of in order to assess and enhance IoT communication performance in 6G work. In 6G IoT systems, effective resource optimization necessitates identifying the critical communication performance metrics. The subsequent items are strategies for enhancing important communication performance indicators include latency, coverage, SE, and EE.

2.1. Latency

In 5G and 6G IoT communication networks, where there are high expectations for real-time data interaction ability to meet user requirements, latency refers to the end-to-end delay. In [11], changes in channel and Task arrival randomness challenges are designed using a Constrained Markov Decision Process (CMDP)-based approach to minimize latency.

2.2. Energy efficiency

Energy consumption is increasing due to the quick expansion of wireless data and IoT devices in 5G and 6G networks, making EE optimization of these networks' IoT communication systems imperative. For UAVs in the satellite-aerial-terrestrial network (SATN), Sami *et al.* [12] created the total power constraint beamforming scheme (TPC-BF) and the per-antenna power constraint beamforming (PPC-BF) scheme to maximize EE with minimal complexity.

2.3. Spectrum efficiency

SE seeks to minimize interference while maximizing spectrum utility. The performance of IoT systems is significantly impacted by SE in [13]. Many SE optimization strategies have been researched recently. In, the authors developed a Weighted Huffman Tree (WHT) method in cognitive networks to give a joint optimization strategy that takes spectrum usage and sensing into account concurrently to increase MAC-layer sensing efficiency. Proposed in, spectrum sensing-based SE optimization is notably identified as the primary method of SE optimization of 5G and 6G IoT networks.

2.4. Bandwidth

Manogaran *et al.* [14] presented a deep Q-network (DQN) technique for improving BA for IoT devices in SDN, which is based on the DRL algorithm. Bandwidth was a major concern when considering about any generation of technology not only in 6G. Throughput and data rate all directly depends on bandwidth, if we utilize the bandwidth at a higher rate, then, these will actually be improved.

2.5. Rate

In 5G and 6G IoT communication systems, there are strong demands for high rates with long-distance transmission. Increasing the data rate is one of the 6G IoT networks' top priorities. Zhou *et al.* [15] described a cooperative decode and forward (DF) relaying method for Simultaneous wireless information and power transfer (SWIPT) based on orthogonal frequency division multiplexing (OFDM). The reconfigurable intelligent surfaces (RIS) technology was employed by the authors in order to boost the pace of UAV systems.

2.6. Joint optimization strategies

Numerous IoT devices have emerged as a result of the development of 5G and 6G communication, creating a number of communication issues for devices with limited network resources that need to use 5G and 6G communication.

2.7. Latency

In 5G and 6G networks, placing too much emphasis on latency could cause other performance indicators to decline. Figure 1 displays a number of latency-related indicators. This section provides illustrations of the joint optimization techniques.

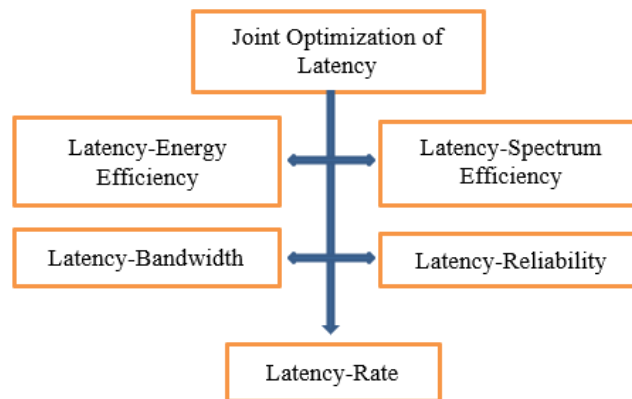


Figure 1. Tradeoff among key indicators

2.8. Latency-energy efficiency

Zhang *et al.* [16] looked at the EE optimization problem of IoT networks in a marine setting with high traffic and constrained resources. The authors of suggested a multi-user multi-task computation offloading architecture in an effort to guarantee EE for MEN and reduce the overall latency of IoT networks.

2.9. Latency-bandwidth reliability rate

Zheng *et al.* [17] created an Opera technique to produce time-varying expander graphs that meet low latency and high bandwidth needs. The authors of suggested a request allocation method based on

particle swarm optimization (PSO) that combines latency control and bandwidth utilization into a combined optimization plan for large-scale situations. Massive MIMO, multi-connectivity, source-channel coding, and protocol design approaches in 5G wireless systems of URLLC were covered by the authors in. The latency and reliability requirements for end-to-end communication are met by the emulation consequences. The authors of talked about an energy-conscious task optimization approach for intelligent transportation systems (ITS) in the URLLC edge computing scenario via cloud networks. The M-parallel look-ahead pointers generation approach was used in to improve rate matching and lower the 5G new radio (NR) system's overall latency. The latency minimum of NOMA users with a link-layer rate maximum is examined by the authors.

2.10. Energy and spectrum efficiency

If EE is given exclusive priority, other 5G and 6G network performance metrics may suffer. Figure 2 displays a number of EE-related metrics. This section provides examples of the combined optimization techniques. Li *et al.* [18] used co-operative spectrum sensing (CSS) for CR networks of future wireless networks to study the SE and EE problem. Many efficient optimization techniques for EE optimization are needed to create a communication network with high EE and high SE. and SE concurrently for IoT connection across 5G and 6G. The systems included in this section. The five articles examine methods for striking a balance between SE and EE in wireless networks, each offering unique solutions suited to certain network situations. This problem is addressed in Papers, respectively, by using sparse RIS-assisted CF MIMO frameworks, mixed-integer nonlinear programming (MINLP), CSS, utility function formulation, and 3D channel modelling.

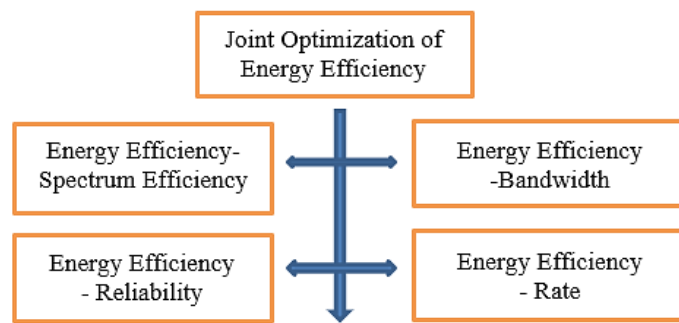


Figure 2. Tradeoff among key Indicators

2.11. Energy and spectrum efficiency rates

The authors of assessed the transmit power, data rate, and energy efficiency of integrated 5G IoT networks. The outcomes validate that the retransmission strategy that was developed enhances energy efficiency for adaptive data rate in internet of things systems. Interference was overlooked, nevertheless. To increase the bit rate in a spread spectrum communication system, they developed a combination optimization problem of spectrum efficiency, decoding speed, and computational complexity.

2.12. Bandwidth

If bandwidth is given too much weight, it may eclipse other indicators' performance in 5G and 6G networks. For instance, increasing bandwidth utility may result in low transmission rates and unreliability of data transfer. That is, optimal dependability, rate, and bandwidth efficiency are not all available at the same time.

2.13. Energy efficiency-bandwidth

The joint optimization problem of energy efficiency in ZigBee-based wireless sensor networks (WSNs) and local area networks (WLANs) with bandwidth optimization has been studied in [19]. Reliability optimization for dense IoT situations in low-power wide area networks (LPWANs) was highlighted by Park *et al.* the outcomes showed that the Choir technique, which resolves signal collisions, might be used to produce low interference, good dependability, and low energy consumption. However, stochastic signals and dynamic interference collide and require greater thought and attention. Figure 3, Tradeoff among key indicators.

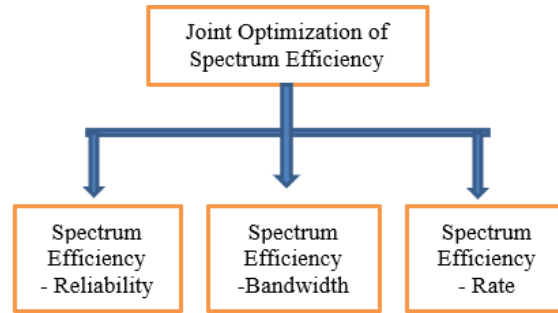


Figure 3. Tradeoff among key indicators

2.14. Energy and spectrum efficiency rates

The authors of assessed the transmit power, data rate, and energy efficiency of integrated 5G IoT networks. The outcomes validate that the retransmission strategy that was developed enhances energy efficiency for adaptive data rate in internet of things systems. Interference was overlooked, nevertheless. To increase the bit rate in a spread spectrum communication system, they developed a combination optimization problem of spectrum efficiency, decoding speed, and computational complexity. Energy-aware optimization is another vital consideration in large-scale 6G IoT deployments. Emerging technologies such as RIS have shown promise, particularly with the development of simultaneous transmission and reflection RIS (STAR-RIS), which enables significant improvements in power efficiency while sustaining throughput [20]. These strategies strengthen the ability of 6G systems to support both green communications and high-performance applications.

2.15. Bandwidth

If bandwidth is given too much weight, it may eclipse other indicators' performance in 5G and 6G networks. For instance, increasing bandwidth utility may result in low transmission rates and unreliability of data transfer. That is, optimal dependability, rate, and bandwidth efficiency are not all available at the same time. Figure 4 displays a number of indicators that are connected to bandwidth. This section provides examples of the combined optimization techniques for bandwidth and other metrics.

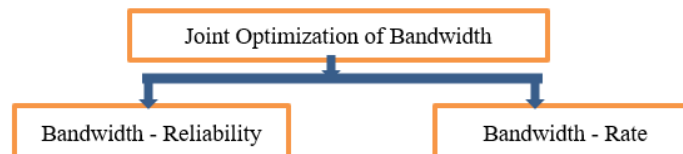


Figure 4. Tradeoff among key indicators

2.16. Bandwidth reliability and rate

Minimal-density parity-check (MDPC) models achieve great reliability and minimal repair bandwidth. When compared to the present Reed-Solomon coding approach, the minimal repair bandwidth concept enhances dependability, as demonstrated by the results of the emulator. The issues with sample rate and bandwidth constraint in deep-spread spectrum satellite communication have been discussed. The results of the emulation show that the interpolation rate matching module technique that was developed can achieve the required sample rate while adhering to bandwidth constraints.

2.17. Reliability-rate

In 5G and 6G networks, optimizing the rate alone may unintentionally overlook other performance parameters. Improving dependability, for instance, can result in a low transmission rate.

3. CHALLENGES OF RESOURCE OPTIMIZATION IN 6G IOT COMMUNICATION SCENARIOS

IoT techniques are becoming more commonplace as 6G technology progresses. To support these IoT devices, we need low latency, high dependability, EE and SE, high rate, and high bandwidth efficiency.

3.1. Uncertain factors scenario

Challenges and proposed solutions: The goal of many research projects has been to develop an ideal algorithm with ideal spectrum sensing and specific channel state in order to improve network performance metrics including interference, throughput, SE, and EE. Practical strategies to reduce transmission latency and increase spectrum sensing accuracy in 6G IoT networks have been put forth in response to the uncertain spectrum sensing and stringent transmission latency requirements.

3.2. Multi-dimension scenario

Challenges and proposed solutions: Due to the scope and complexity of applications, traditional terrestrial wireless communication has recently grown explosively, making it difficult to meet the sophisticated demands of future networks. In order to compensate for the inherent shortcomings of cellular cells that rely on ground resources, satellites and near-space vehicles are used to establish space and space communication systems.

3.3. Ultra-dense scenario

Challenges and proposed solutions: Applying terahertz communications with higher frequency bands as a novel remedy for the present 6G technology capacity limitations are difficult, particularly given the spectrum scarcity brought on by the dense ground communication networks in 6G IoT. An efficient cache-enabled MEN architecture was in place to counter the massive data traffic and numerous terminal units. But given the aforementioned difficulties, future wireless network development still has to pay more attention to 6G communication-based ultra-dense network integration.

3.4. Dynamic resource scenario

Challenges and proposed solutions: It becomes difficult to improve the wireless connection latency and the FL model training latency in IoT systems by achieving more reasonable network resource allocation because different communication distances will result in different strengths of the wireless data received by the signal receiver. The resource allocation approach in the low-power IoT system based on FL is primarily based on the topology of a static wireless network, in which the IoT terminal device is fixed in the network and is not mobile.

3.5. Multi-users scenario

Challenges and proposed solutions: By focusing solely on the communication mode of a single user, it has become hard to stay up to date with the needs of current IoT equipment due to the emergence of several new sectors and services in recent years. Numerous recent publications have addressed resource efficiency in a single baseband unit (BBU) situation. On the other hand, single-user communication systems have restricted bandwidth issues, latency, and communication restrictions.

4. FUTURE RESEARCH DIRECTIONS OF RESOURCE OPTIMIZATION IN 6G INTERNET OF THINGS COMMUNICATION

The proposal for enhancements in the joint optimization of the major indicators provides a comprehensive understanding of the prospect study's vision for IoT on 5G and 6G networks.

- a. Multi-indicators joint optimization: Future 5G and 6G networks will need to conduct extensive research on the IoT's transmission technology, which will result in more demanding service requirements for IoT devices.
- b. Decentralized architecture-based men: Due to high user density in dense scenarios of ground hotspots like office buildings and large shopping malls, the traditional centralized resource allocation method has a high computational complexity, and the iterative elements of the distributed algorithm require a large number of interactions to achieve convergence.
- c. AI-Based MI/DI: In the future, sophisticated ML or DL algorithms will be used to examine the relationship between resource utility and network performance. Currently, some research mainly examines the data utility of network resources under specific indicators.
- d. FI Framework: The impact of node mobility and learning performance is not taken into account in the current resource optimization algorithms, which are intended for static IoT scenarios.
- e. Blockchain: With the use of spectrum sharing, current technologies may efficiently increase resource utilization in order to fulfill the vast spectrum demand of numerous IoT devices connecting to 5G and 6G networks. Blockchain has drawn a lot of interest lately.
- f. Dynamic modulation and coding mode: Studies already conducted look at cache unloading, beamforming, and other methods for enhancing IoT network performance. In 6G networks, a variety of cutting-edge bandwidth allocation algorithms will be coupled with cutting-edge modulation and coding methods.

- g. Novel network architecture: The planned smart integration identifier network architecture is eager to be integrated with the 6G IoT networks. In the smart integration identifier network architecture, smart identification services can be implemented using the knowledge areas concept.
- h. Quantum networks: Enhancing resource optimization in quantum networks is a vital area of research and development to ensure efficient utilization of quantum resources such as entangled photons, qubits, and communication channels.

5. KEY STRATEGIES AND TECHNIQUES

Below are key strategies and techniques used to optimize resources in quantum networks:

- a. Dynamic resource allocation: Adaptive routing protocols, implement dynamic routing algorithms that adapt based on network conditions, such as channel noise or resource availability. Priority-based scheduling, assign priority to critical tasks like quantum key distribution (QKD) over less time-sensitive operations.
- b. Entanglement management: Entanglement swapping, efficiently utilize entanglement swapping at quantum repeater nodes to extend the range of entanglement. Quantum error correction (QEC), use QEC codes to detect and correct errors in qubits, allowing for the reuse of resources. Noise-adaptive protocols, tailor protocols to the noise characteristics of the environment, minimizing resource wastage.

6. REMOTE LOCATION SURGERY

A surgeon can operate on a patient remotely, sometimes referred to as cyber surgery or tele surgery, even if the patient and the surgeon are not physically present in the same place. It's a type of virtual presence. A master controller, often known as a console, one or more arms that are operated by the surgeon in [21], and a sensory system that provides input to the user make up a typical robotic surgical system. Robotics, management information systems, and telecommunications, including fast data connections, all play a part in remote surgery. Even though robotic surgery is a reasonably well-established specialty, most robotic surgeons operate under the supervision of surgeons at the surgical site. Surgeons who do remote surgery do it from a location where the physical distance between them and their patients is less significant. It claims to provide patients' access to the knowledge of specialized surgeons available to them anywhere in the world, eliminating the need for them to leave their neighborhood hospital.

In this work, the facilities provided by the remote location surgery was utilized and using 6G technology it has been accelerated to even further. The remote location surgery actually suffers from latency and data rates which were improved greatly using current 6G technology. And more over the 6G not only provided the latency better than existing technologies but it has provided the necessary parameters like high data rate which offered the high-quality transmissions on either sides in order to avoid those minor or minute errors which may result huge results in patient's life. In [22] using 6G-enabled IoT networks for remote location surgery represents a major advancement in the field of telemedicine. As healthcare moves toward more decentralized and digital systems, the need for robust and intelligent communication infrastructure becomes increasingly urgent. In study [23] remote surgical procedures, where every millisecond of delay can affect outcomes, communication technology must support extremely low latency and high reliability. Sixth-generation wireless networks are designed to meet such exacting demands by offering ultra-reliable low-latency communication (URLLC), massive machine-type communication (mMTC), and enhanced mobile broadband (eMBB) in a single unified framework.

The results obtained from the throughput and data rate analysis strongly validate the performance capabilities of 6G IoT networks, particularly in the context of remote location surgery. As observed in the throughput trend from Figure 5, the 6G system consistently maintained high data transmission rates over time without notable degradation in [24]. This level of sustained throughput is vital in real-time surgical applications, where even brief communication delays or data loss can have critical consequences. The stability and resilience of 6G, as evidenced by this result, demonstrate that it can reliably support the continuous and intensive data exchange required during remote procedures, marking a significant advancement over earlier wireless technologies. Similarly, the data rate behavior shown in Figure 6 further confirms the efficiency and reliability of 6G in handling high-demand scenarios in [25]. The data rate remained steady across the test duration, reinforcing the network's capability to provide uninterrupted service, which is essential for the precision and responsiveness needed in remote surgical operations. These findings validate the conclusion that integrating remote location surgery into a 6G IoT environment is not only feasible but also practically reliable. The ability of 6G to deliver both consistent throughput and data rate underlines its readiness for critical real-time applications, opening the path for future innovations in connected healthcare and other latency-sensitive domains.

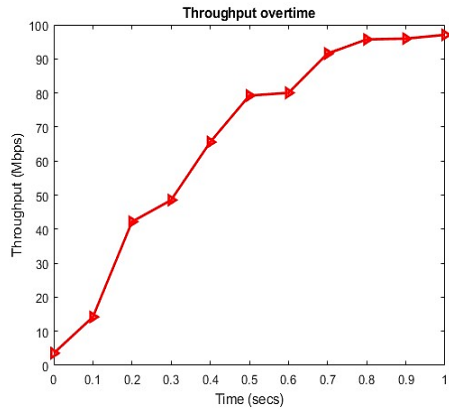


Figure 5. Plot of data rate overtime

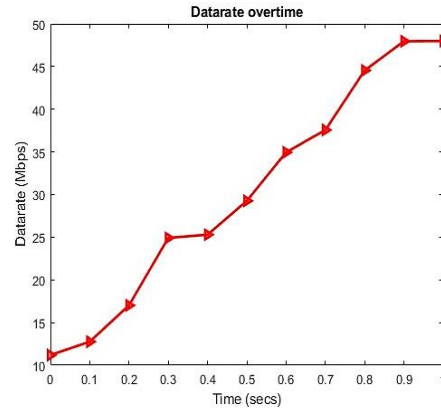


Figure 6. Plot of throughput overtime

7. RESULTS AND DISCUSSION

In this section, it is explained the results of research and at the same time is given the comprehensive discussion. Results can be presented in figures, graphs, tables and others that make the reader understand easily [16], [17]. The discussion can be made in two sub-sections.

7.1. Throughput performance and reliability of 6G networks

The data presented in Figure 5 indicates a clear and consistent increase in throughput over time when using 6G networks, highlighting their superior efficiency and long-term stability compared to previous wireless technologies. Unlike earlier generations that tend to experience throughput degradation during prolonged usage, 6G maintains a high and steady data rate, which is essential for applications requiring uninterrupted, real-time communication such as remote location surgery. The graph shows that even as operational time extends, 6G sustains performance without significant drops, validating its enhanced resource management and network optimization capabilities. This consistent throughput confirms that 6G is not only faster but also more reliable, making it highly suitable for critical scenarios where continuous data flow is crucial for safety and precision.

$$\text{datarate} = \frac{\text{total amount of data}}{\text{overtime}} \quad (1)$$

7.2. Stable data rate trends in 6G networks

Figure 6 illustrates the data rate trend over time in a 6G environment, showing a consistent and stable performance that underscores the unique efficiency of 6G technology. Unlike previous generations, where data rates may fluctuate due to congestion, latency, or bandwidth limitations, the plot demonstrates that 6G is capable of maintaining a high data rate across extended operational periods. This stability is crucial for applications that require constant high-speed communication, such as remote location surgery, where any drop-in data rate could compromise precision and safety. The graph validates 6G's ability to deliver uninterrupted and reliable data flow, highlighting its advanced capabilities in handling high-demand, real-time tasks with greater consistency than legacy systems.

$$\text{throughput} = \frac{\text{total amount of data between tx and rx}}{\text{overtime}} \quad (2)$$

8. CONCLUSION

To meet the demanding requirements of 6G IoT networks, resource optimization remains a critical and evolving area of study. Through a comprehensive analysis of both recent and past research, various techniques, performance indicators, and application-specific strategies have been explored to enhance network efficiency. The successful implementation of remote location surgery within a 6G IoT framework further reinforces the importance of optimized resource management. As validated by the throughput and data rate results shown in Figures 5 and 6, the 6G environment maintained consistently high-performance levels throughout the operational timeline. This sustained delivery of essential network metrics confirms that 6G provides the necessary conditions for real-time, precision-based applications such as remote surgery. The findings not only demonstrate the technical feasibility but also open the door for broader integration of remote medical procedures within next-generation wireless IoT systems.

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Md Asif	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓			
Tan Kaun Tak	✓	✓	✓	✓	✓	✓			✓	✓				
Pravin R. Kshirsagar						✓	✓			✓		✓	✓	✓

C : Conceptualization

M : Methodology

So : Software

Va : Validation

Fo : Formal analysis

I : Investigation

R : Resources

D : Data Curation

O : Writing - Original Draft

E : Writing - Review & Editing

Vi : Visualization

Su : Supervision

P : Project administration

Fu : Funding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

REFERENCES

- [1] R. Hassan, F. Qamar, M. K. Hasan, A. H. M. Aman, and A. S. Ahmed, "Internet of things and its applications: A comprehensive survey," *Symmetry*, vol. 12, no. 10, pp. 1–29, 2020, doi: 10.3390/sym12101674.
- [2] C. X. Wang *et al.*, "On the road to 6G: Visions, requirements, key technologies and testbeds," *IEEE Communications Surveys and Tutorials*, vol. 25, no. 2, pp. 905–974, 2023, doi: 10.1109/COMST.2023.3249835.
- [3] A. M. H. Alibraheemi *et al.*, "A survey of resource management in D2D communication for B5G networks," *IEEE Access*, vol. 11, pp. 7892–7923, 2023, doi: 10.1109/ACCESS.2023.3238799.
- [4] F. Qamar, K. B. Dimyati, M. H. D. N. Hindia, K. A. Bin Noordin, and A. M. Al-Samman, "A comprehensive review on coordinated multi-point operation for LTE-A," *Computer Networks*, vol. 123, pp. 19–37, 2017, doi: 10.1016/j.comnet.2017.05.003.
- [5] F. Guo, F. R. Yu, H. Zhang, X. Li, H. Ji, and V. C. M. Leung, "Enabling massive IoT toward 6G: A comprehensive survey," *IEEE Internet of Things Journal*, vol. 8, no. 15, pp. 11891–11915, 2021, doi: 10.1109/JIOT.2021.3063686.
- [6] S. H. A. Kazmi, F. Qamar, R. Hassan, K. Nisar, and B. S. Chowdhry, "Survey on joint paradigm of 5G and SDN emerging mobile technologies: Architecture, security, challenges and research directions," *Wireless Personal Communications*, vol. 130, no. 4, pp. 2753–2800, 2023, doi: 10.1007/s11277-023-10402-7.
- [7] S. Malathy *et al.*, "A review on energy management issues for future 5G and beyond network," *Wireless Networks*, vol. 27, no. 4, pp. 2691–2718, 2021, doi: 10.1007/s11276-021-02616-z.
- [8] G. Manogaran and B. S. Rawal, "An efficient resource allocation scheme with optimal node placement in IoT-fog-cloud architecture," *IEEE Sensors Journal*, vol. 21, no. 22, pp. 25106–25113, 2021, doi: 10.1109/JSEN.2021.3057224.
- [9] H. F. Alhashimi *et al.*, "Survey on AI-enabled resource management for 6G heterogeneous networks: recent research, challenges, and future trends," *Computers, Materials & Continua*, vol. 83, no. 3, pp. 3585–3622, 2025, doi: 10.32604/cmc.2025.062867.
- [10] A. Aldrees, H. Min, Y. I. Daradkeh, A. K. Dutta, and M. Anjum, "Optimization of 6G resource allocation using CyberTwin function-based service enhancement scheme," *EURASIP Journal on Wireless Communications and Networking*, vol. 2025, no. 1, p. 30, May 2025, doi: 10.1186/s13638-025-02444-1.
- [11] M. Alsabah *et al.*, "6G wireless communications networks: A comprehensive survey," *IEEE Access*, vol. 9, pp. 148191–148243, 2021, doi: 10.1109/ACCESS.2021.3124812.
- [12] H. Sami, H. Otrok, J. Bentahar, and A. Mourad, "AI-based resource provisioning of IoE services in 6G: A deep reinforcement learning approach," *IEEE Transactions on Network and Service Management*, vol. 18, no. 3, pp. 3527–3540, 2021, doi: 10.1109/TNSM.2021.3066625.
- [13] D. K. Jain, S. K. S. Tyagi, S. Neelakandan, M. Prakash, and L. Natrayan, "Metaheuristic optimization-based resource allocation technique for cybertwin-driven 6G on IoE environment," *IEEE Transactions on Industrial Informatics*, vol. 18, no. 7, pp. 4884–4892, 2022, doi: 10.1109/TII.2021.3138915.
- [14] G. Manogaran, T. N. Nguyen, J. Gao, and P. M. Kumar, "Deep learning-based service distribution model for wireless network assisted Internet of Everything," *IEEE Transactions on Network Science and Engineering*, vol. 9, no. 5, pp. 3004–3014, 2022, doi: 10.1109/TNSE.2022.3155943.
- [15] C. Zhou *et al.*, "Deep reinforcement learning for delay-oriented IoT task scheduling in SAGIN," *IEEE Transactions on Wireless Communications*, vol. 20, no. 2, pp. 911–925, 2021, doi: 10.1109/TWC.2020.3029143.
- [16] H. Zhang, H. Zhang, W. Liu, K. Long, J. Dong, and V. C. M. Leung, "Energy efficient user clustering, hybrid precoding and

- power optimization in terahertz MIMO-NOMA systems,” *IEEE Journal on Selected Areas in Communications*, vol. 38, no. 9, pp. 2074–2085, 2020, doi: 10.1109/JSAC.2020.3000888.
- [17] X. Zheng, S. Huang, X. Li, and Y. Zhou, “Improving sensing efficiency by dynamic spectrum aggregation with utilization constraints,” *International Conference on Signal Processing Proceedings, ICSP*, vol. 2020-Decem, pp. 456–461, 2020, doi: 10.1109/ICSP48669.2020.9320969.
- [18] S. Li, B. Duo, X. Yuan, Y. C. Liang, and M. Di Renzo, “Reconfigurable intelligent surface assisted UAV communication: Joint trajectory design and passive beamforming,” *IEEE Wireless Communications Letters*, vol. 9, no. 5, pp. 716–720, 2020, doi: 10.1109/LWC.2020.2966705.
- [19] J. J. Park, J. H. Moon, K. Y. Lee, and D. I. Kim, “Transmitter-oriented dual-mode SWIPT with deep-learning-based adaptive mode switching for IoT sensor networks,” *IEEE Internet of Things Journal*, vol. 7, no. 9, pp. 8979–8992, 2020, doi: 10.1109/JIOT.2020.2999892.
- [20] A. Alqahtani, N. Taneja, A. Taneja, and N. Alqahtani, “Energy aware resource management in 6G IoT networks using STAR RIS,” *Scientific Reports*, vol. 15, no. 1, p. 20941, Jul. 2025, doi: 10.1038/s41598-025-05338-w.
- [21] A. M. Seid, G. O. Boateng, S. Anokye, T. Kwantwi, G. Sun, and G. Liu, “Collaborative computation offloading and resource allocation in multiUAV-assisted IoT networks: A deep reinforcement learning approach,” *IEEE Internet of Things Journal*, vol. 8, no. 15, pp. 12203–12218, 2021, doi: 10.1109/JIOT.2021.3063188.
- [22] D. Kushwaha, S. Redhu, and R. M. Hegde, “Low latency federated learning over wireless edge networks via efficient bandwidth allocation,” *2021 IEEE 8th World Forum on Internet of Things*, 2022, doi: 10.1109/WF-IoT54382.2022.10152237.
- [23] A. Shahini, A. Kiani, and N. Ansari, “Energy efficient resource allocation in EH-Enabled CR networks for IoT,” *IEEE Internet of Things Journal*, vol. 6, no. 2, pp. 3186–3193, 2019, doi: 10.1109/JIOT.2018.2880190.
- [24] F. Yassine, M. El Helou, S. Lahoud, and O. Bazzi, “Performance of narrowband IoT link adaptation with rate and energy objectives,” *2021 IEEE 3rd International Multidisciplinary Conference on Engineering Technology*, pp. 6–10, 2021, doi: 10.1109/IMCET53404.2021.9665562.
- [25] Y. Cao, A. Wang, G. Sun, and L. Liu, “Average transmission rate and energy efficiency optimization in UAV-assisted IoT,” *IEEE Wireless Communications and Networking Conference, WCNC*, 2023, doi: 10.1109/WCNC55385.2023.10119068.

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