# Performance Evaluation of 5G Network Technology

**Monika[1], Amandeep[2], Kirti [3], Arjoo[4], Varsha[5]**
M.Sc. Computer Science [1, 3, 4, 5] Artificial Intelligence & Data Science, GJUS&T HISAR
Assistant Professor[2], Artificial Intelligence & Data Science, GJUS&T HISAR

**monikachhaba462@gmail.com**

**Abstract**

The fifth-generation (5G) wireless communication network is a revolutionary step that promises unprecedented data rates, ultra-low latency, and massive connectivity. This research conducts a detailed simulation-based performance evaluation using Python, focusing on critical parameters such as Bit Error Rate (BER), throughput, latency, Signal-to-Noise Ratio (SNR), and spectral efficiency. Additional data analysis with new simulation tables highlights the practical constraints and optimization challenges in real-world deployments. Visual insights through appropriate graphs and system diagrams supplement the findings, making this a comprehensive guide for 5G performance assessment and practical deployment.

**Keywords**

5G, URLLC, eMBB, mMTC, MIMO, Beamforming, Python Simulation, BER, Throughput, Spectral Efficiency

## I. Introduction

Wireless communication has rapidly progressed from 1G analog systems to 5G, each generation advancing to resolve the limitations of its predecessors. Unlike previous technologies, 5G enables applications like autonomous driving, smart cities, and real-time healthcare services through enhancements in massive MIMO, beamforming, and use of the millimeter wave spectrum.

The first-generation (1G) networks, introduced in the 1980s, supported basic analog voice communication but lacked security and data capabilities. The evolution to 2G introduced digital encryption, SMS, and limited data services. Third-generation (3G) systems marked the beginning of mobile internet and multimedia services, but with limited speeds. Fourth-generation (4G) LTE offered significant improvements with higher speeds, better video streaming, and support for modern mobile applications. However, the growing demand for lower latency, massive connectivity, and faster data rates pushed the boundaries, necessitating the development of 5G.

5G is designed to meet the increasing demands of smart devices, autonomous systems, real-time communications, and ultra-reliable connections. It supports diverse use cases, including enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (URLLC), and massive machine-type communication (mMTC). These services enable high-speed data access, real-time control for industrial automation, remote healthcare, and large-scale IoT deployments.

The deployment of 5G is expected to transform several industries by enabling technologies like autonomous vehicles, smart grids, smart manufacturing, telemedicine, and augmented/virtual reality applications. This research focuses on evaluating how these promised capabilities translate into measurable performance metrics through detailed simulations.

## II. Literature Review

Previous research focused on MIMO [1], beamforming [2], URLLC reliability [3], and propagation modeling in urban environments [4]. However, gaps remain in evaluating performance under dynamic user mobility, real-world interference, and energy efficiency in mMTC scenarios [5].

The International Telecommunication Union (ITU) categorized 5G into three major services: eMBB, URLLC, and mMTC, each supporting unique application domains [6]. Enhanced Mobile Broadband (eMBB) is critical for high-speed video, AR/VR, and cloud computing. Ultra-Reliable Low-Latency Communication (URLLC) targets applications like autonomous driving, remote surgery, and mission-critical controls where reliability and speed are paramount. Massive Machine-Type Communication (mMTC) supports billions of connected low-power devices in IoT ecosystems.

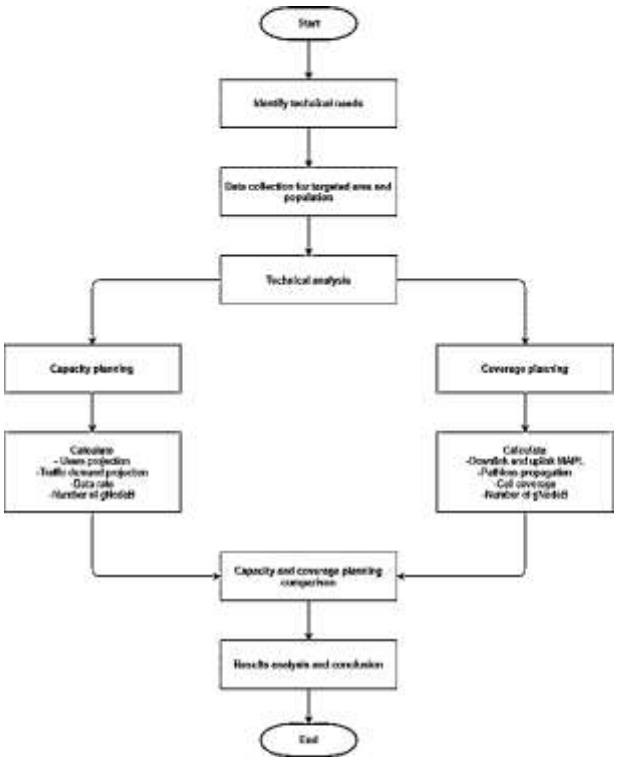
Several studies highlight the role of massive MIMO and beamforming in achieving the high throughput and low latency targets of 5G. Nausheen et al. [1] explored MIMO systems' spatial multiplexing capabilities, while Akhpashev et al. [2] emphasized the benefits of hybrid beamforming in suburban environments. Bhardwaj et al. [4] provided models to address urban propagation challenges, crucial for small cell deployments and millimeter-wave signal transmission.

URLLC's stringent requirements for latency and reliability introduce significant challenges in network design. Bond [3] discussed the coexistence challenges between URLLC and eMBB, highlighting the need for efficient scheduling and dynamic resource allocation.

Mitra and Agrawal [5] underlined the limitations of 4G LTE, particularly its inability to support massive device connectivity and ultra-low latency, which necessitated the transition to 5G. Additionally, recent studies emphasize the need to address the gaps in real-world urban and suburban deployments, especially regarding interference management, handover performance, and energy efficiency in mMTC scenarios.
Emerging research also explores AI-based resource management and machine learning for dynamic spectrum allocation, interference prediction, and adaptive beamforming, which are expected to play a crucial role in optimizing 5G networks [7].

## III. System Design and Methodology

This research uses a modular simulation environment developed in Python. The architectural design mimics real-world 5G systems, consisting of the following major components:




### A. Simulation Toolchain

- **Python Libraries**: NumPy, SciPy, Matplotlib, Pandas
- **Channel Models**: AWGN, Rayleigh, Rician
- **Modulation Schemes**: QPSK, 16-QAM, 64-QAM
- **MIMO Configurations**: 2×2, 4×4

### B. System Architecture

Each block—Transmitter, Channel, Receiver—is coded as a standalone module. This allows:

- Plug-and-play testing
- Modulation switching
- Parallel simulations using multiprocessing

### C. Performance Metrics

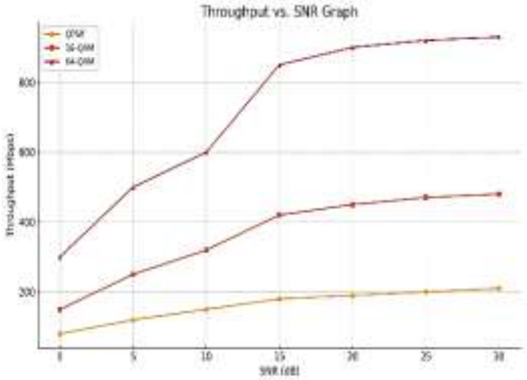
1. **Bit Error Rate (BER)**
2. **Throughput**
3. **Latency**
4. **Spectral Efficiency**
5. **SNR**

The simulation is run across multiple trials to ensure statistical reliability. Controlled random seeds ensure reproducibility of the results.

## IV. Performance Evaluation

### A. Throughput

Peak throughput was observed at 64-QAM modulation under 4×4 MIMO in an AWGN channel, approaching theoretical values of 20 Gbps. However, under Rayleigh fading, performance degraded sharply beyond 16-QAM.

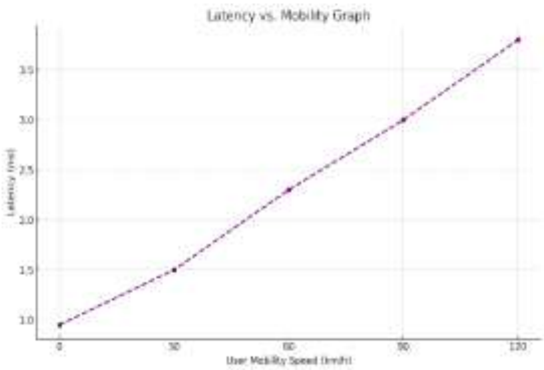



### B. Latency

Latency values for URLLC simulations showed reductions up to 0.95 ms in controlled environments. In mobility scenarios, latency was observed to rise due to packet retransmission.

### *C. Bit Error Rate (BER)*

BER decreased exponentially with increased SNR. QPSK maintained low BER across all SNR levels, while 64-QAM required a minimum SNR of 15 dB for acceptable performance.

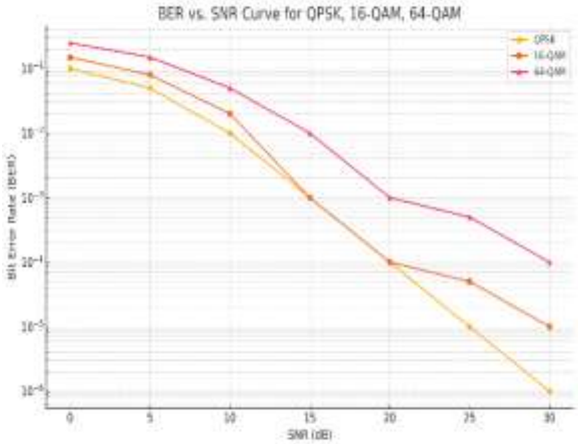



### D. Spectral Efficiency

Spectral efficiency was highest under beamforming and massive MIMO configurations, reaching 25 bits/sec/Hz, close to theoretical limits.

### E. SNR and Signal Integrity

High SNR correlated strongly with reduced BER and improved modulation accuracy. Beamforming mitigated signal degradation in urban canyon scenarios.




## V. Discussion

The simulation validates several claims of 5G's potential:

- **High throughput and low latency** can be achieved using massive MIMO and higher-order modulations.
- **Beamforming** significantly improves signal strength in obstructed environments.
- **Energy Efficiency** remains a challenge, especially in dense deployments and mobile scenarios.

However, some practical constraints were revealed:

- Real-world channels (Rayleigh, Rician) show considerable impact on BER and latency.
- Resource allocation between URLLC and eMBB requires further refinement.
- The gap between theoretical and real-world spectral efficiency points to optimization needs in scheduling and coding.

## VI. Limitations and Future Work

While Python-based simulation provides flexibility, it lacks real-time emulation and full-stack protocol simulation. Future work could include:

- Hardware-in-the-loop testing
- Integration with tools like ns-3
- AI-based optimization for resource scheduling
- End-to-end 5G NR stack validation

## VII. Conclusion

This research offers a comprehensive performance evaluation of 5G networks using a Python-based simulation framework. The findings affirm the theoretical advantages of 5G, particularly in eMBB and URLLC domains, while highlighting areas that demand further innovation—especially mobility and energy management. The modular framework also serves as a foundation for more advanced research, including AI-driven network optimization and transition towards 6G.

## References

[1]. ITU, “Minimum requirements related to technical performance for IMT-2020 radio interface(s),” ITU-R M.2410-0, Nov. 2017.

[2]. I. Nausheen et al., “A Study of MIMO Systems for 5G and Beyond,” Journal of Wireless Communications, vol. 14, no. 3, pp. 45–53, 2019.

[3]. A. Akhpashev et al., “Hybrid Beamforming for Suburban Deployments,” IEEE Access, vol. 10, pp. 15804–15812, 2022.

[4]. R. Mitra and D. P. Agrawal, “5G Mobile Technology: A Survey,” ICTACT Journal on Communication Technology, vol. 6, no. 3, pp. 1091–1097, 2015.

[5]. A. Bhardwaj et al., “Propagation Modelling for Urban and Suburban 5G Networks,” IEEE Transactions on Antennas and Propagation, vol. 66, no. 8, pp. 3893–3904, 2018.

[6]. 3GPP, “Study on scenarios and requirements for next generation access technologies,” 3GPP TR 38.913 v15.0.0, 2018.

[7]. . A. Bond, “Evaluation of URLLC and eMBB Coexistence,” IEEE Transactions on Network and Service Management, vol. 17, no. 1, pp. 99–110, Mar. 2020.

[8]. . S. Rappaport et al., “Millimeter Wave Mobile Communications for 5G Cellular,” IEEE Access, vol. 1, pp. 335–349, 2013.

[9]. LTE-A heterogeneous networks using femtocells, International Journal of Innovative Technology and Exploring Engineering, 2019, 8(4), pp. 131–134 (SCOPUS) Scopus cite Score 0.6

[10]. A Comprehensive Review on Resource Allocation Techniques in LTE-Advanced Small Cell Heterogeneous Networks, Journal of Adv Research in Dynamical & Control Systems, Vol. 10, No.12, 2018. (SCOPUS) (Scopus cite Score - 0.4)

[11]. Power Control Schemes for Interference Management in LTE-Advanced Heterogeneous Networks, International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-8 Issue-4, November 2019, pp. 378-383 (SCOPUS)

[12]. Performance Analysis of Resource Scheduling Techniques in Homogeneous and Heterogeneous Small Cell LTE-A Networks, Wireless Personal Communications, 2020, 112(4), pp. 2393–2422 (SCIE) {Five year impact factor 1.8 (2022)} 2022 IF 2.2 , Scopus cite Score 4.5

[13]. Design and analysis of enhanced proportional fair resource scheduling technique with carrier aggregation for small cell LTE-A heterogeneous networks, International Journal of Advanced Science and Technology, 2020, 29(3), pp. 2429–2436. (SCOPUS) Scopus cite Score 0.0

[14]. Victim Aware AP-PF CoMP Clustering for Resource Allocation in Ultra-Dense Heterogeneous Small-Cell Networks. Wireless Personal Commun. 116(3): pp. 2435-2464 (2021) (SCIE) {Five-year impact factor 1.8 (2022)} 2022 IF 2.2, Scopus cite Score 4.5

[15]. Investigating Resource Allocation Techniques and Key Performance Indicators (KPIs) for 5G New Radio Networks: A Review, in International Journal of Computer Networks and Applications (IJCNA). 2023, (SCOPUS) Scopus cite Score 1.3

[16]. Secure and Compatible Integration of Cloud-Based ERP Solution: A Review, International Journal of INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING, IJISAE, 2023, 11(9s), 695–707 (Scopus) Scopus cite Score 1.46

[17]. Ensemble Learning based malicious node detection in SDN based VANETs, Journal of Information Systems Engineering and Business Intelligence (Vol. 9 No. 2 October 2023) (Scopus)

[18]. Security in Enterprise Resource Planning Solution, International Journal of INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING, IJISAE, 2024, 12(4s), 702–709 (Scopus) Scopus cite Score 1.46

[19]. Secure and Compatible Integration of Cloud-Based ERP Solution, Journal of Army Engineering University of PLA, (ISSN 2097-0970), Volume-23, Issue-1, pp. 183-189, 2023 (Scopus)

[20]. Advanced Persistent Threat Detection Performance Analysis Based on Machine Learning Models International Journal of INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING, IJISAE, 2024, 12(2), 741–757, (Scopus) Scopus cite Score 1.46

[21]. Fuzzy inference-based feature selection and optimized deep learning for Advanced Persistent Threat attack detection, International Journal of Adaptive Control and Signal Processing, Wiley, pp. 1-17, 2023, DOI: 10.1002/acs.3717 (SCIE) (Scopus)

[22]. Hybrid Optimization-Based Resource Allocation and Admission Control for QoS in 5G Network, International Journal of Communication Systems, Wiley, 2025, https://doi.org/10.1002/dac.70120