ISSN: 2971-7760 | VOL 7, ISS 1 | 06 AUGUST 2026
https://doi.org/10.5281/zenodo.21820030
NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

Performance Analysis of 5G Communication Systems in Urban Environments

Aliyu Kallamu

Department of Electrical Engineering, Federal Polytechnic Mubi, Adamawa State, Nigeria

kallamualiyu61@gmail.com

ABSTRACT

The deployment of fifth-generation (5G) communication systems has transformed wireless communications by providing ultra-high data rates, ultra-low latency, massive connectivity, and improved spectrum efficiency. These capabilities have accelerated the development of smart cities, intelligent transportation systems, industrial automation, Internet of Things (IoT) applications, and real-time digital services. Despite these advancements, the performance of 5G networks in dense urban environments remains affected by challenges such as severe signal attenuation, multipath propagation, building penetration losses, network congestion, and interference resulting from high user density. Consequently, evaluating the operational performance of 5G communication systems under urban deployment conditions has become essential for optimizing network planning and improving service quality. This study presents a comprehensive review and performance analysis of 5G communication systems in urban environments by examining enabling technologies including Massive Multiple-Input Multiple-Output (Massive MIMO), millimeter-wave (mmWave) communication, beamforming, network slicing, and small-cell deployment. Recent empirical studies and international standards are synthesized to evaluate their influence on throughput, latency, coverage, spectral efficiency, energy efficiency, and Quality of Service (QoS). The review demonstrates that although 5G significantly outperforms previous mobile generations, optimal urban performance depends on intelligent network design, dense infrastructure deployment, adaptive resource allocation, and artificial intelligence-enabled network optimization. The study further identifies current implementation challenges and discusses emerging technologies that will support future enhancements in urban wireless communication systems. The findings provide useful insights for researchers, network operators, policymakers, and telecommunications engineers involved in the planning and deployment of resilient and high-performance 5G networks.

Keywords: 5G communication, urban environments, Massive MIMO, millimeter-wave, beamforming, network slicing, Quality of Service, wireless communication.

INTRODUCTION

ISSN: 2971-7760 | VOL 7, ISS 1 | 06 AUGUST 2026
https://doi.org/10.5281/zenodo.21820030
NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

The rapid evolution of wireless communication technologies has fundamentally transformed the way individuals, businesses, and governments exchange information. From first-generation (1G) analogue systems to the emergence of fifth-generation (5G) mobile networks, each generation has introduced significant improvements in communication capacity, data transmission speed, reliability, and service delivery. Among these, **5G** represents the most significant advancement by supporting enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (URLLC), and massive machine-type communication (mMTC), thereby enabling next-generation digital services across multiple sectors (International Telecommunication Union [ITU], 2024; 3GPP, 2024).

Urban environments are experiencing unprecedented growth in mobile data traffic due to increasing smartphone adoption, cloud-based services, Internet of Things (IoT) devices, autonomous transportation, smart infrastructure, and digital commerce. Consequently, existing wireless networks are under growing pressure to provide higher capacity, lower latency, broader coverage, and improved Quality of Service (QoS). To address these demands, 5G incorporates advanced technologies such as **Massive MIMO**, **millimeter-wave (mmWave) communication**, **beamforming**, **network slicing**, **edge computing**, and **small-cell architectures**, which collectively improve spectral efficiency, reduce transmission delays, and support high-density connectivity (GSMA, 2025; Ericsson, 2024).

Despite these technological advancements, achieving consistent 5G performance in dense urban environments remains challenging. High-rise buildings, dense infrastructure, multipath propagation, shadow fading, signal blockage, and user mobility significantly affect network performance, particularly within high-frequency mmWave bands. In addition, increasing user density creates greater demand for spectrum resources, requiring intelligent radio resource management and adaptive network optimization to maintain reliable communication (Nokia, 2024; Huawei, 2025).

Recent developments in artificial intelligence (AI), machine learning, software-defined networking (SDN), network function virtualization (NFV), and edge computing have further enhanced the capabilities of urban 5G networks. AI-driven traffic prediction, intelligent beam management, dynamic spectrum allocation, and automated fault detection improve network efficiency, reduce operational costs, and optimize service quality under varying traffic conditions (IEEE Communications Society, 2024). These technologies are becoming essential for supporting smart city applications, intelligent transportation systems, Industry 4.0, telemedicine, immersive multimedia services, and other latency-sensitive applications.

Although numerous studies have examined individual components of 5G technology, many focus primarily on specific technologies or isolated

ISSN: 2971-7760 | VOL 7, ISS 1 | 06 AUGUST 2026
https://doi.org/10.5281/zenodo.21820030
NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

performance metrics. Comparatively fewer studies provide an integrated assessment of how the core technologies collectively influence communication performance within dense urban environments. As cities continue to expand and wireless communication demands increase, there is a growing need for comprehensive analyses that synthesize recent developments, identify implementation challenges, and highlight strategies for improving network performance.

This study addresses this gap by reviewing and analyzing the performance of 5G communication systems in urban environments. Specifically, it examines the enabling technologies underpinning 5G networks, evaluates their effects on key performance indicators such as throughput, latency, spectral efficiency, coverage, and Quality of Service, and discusses emerging solutions for enhancing future urban wireless communications. The findings provide practical insights for telecommunications engineers, network operators, policymakers, and researchers seeking to optimize 5G deployment and support the evolution of next-generation wireless communication systems.

LITERATURE REVIEW

The deployment of fifth-generation (5G) communication systems has significantly transformed wireless communication by delivering ultra-high data rates, ultra-low latency, enhanced reliability, and massive connectivity. Unlike previous generations that primarily focused on voice and mobile broadband services, 5G is designed to support emerging applications such as smart cities, autonomous transportation, Industry 4.0, healthcare, virtual reality, and the Internet of Things (IoT) (International Telecommunication Union [ITU], 2024; 3GPP, 2024). These capabilities position 5G as the enabling infrastructure for next-generation digital transformation.

One of the defining characteristics of 5G is its use of **Massive Multiple-Input Multiple-Output (Massive MIMO)** technology. Massive MIMO employs a large number of antennas at base stations to serve multiple users simultaneously, significantly improving spectral efficiency, network capacity, and signal reliability while reducing interference (Björnson & Sanguinetti, 2023). Combined with adaptive beamforming, Massive MIMO enables precise signal transmission toward intended users, thereby improving coverage and reducing unnecessary energy consumption, particularly within densely populated urban environments.

Another key enabling technology is **millimeter-wave (mmWave) communication**, which utilizes high-frequency spectrum bands to provide multi-gigabit transmission speeds and increased network capacity (Rappaport et al., 2022). Although mmWave offers substantial bandwidth advantages, its propagation characteristics make it highly susceptible to attenuation, building blockage, rainfall, and signal absorption. Consequently, urban deployments require dense small-cell architectures and intelligent beam management to maintain reliable connectivity and consistent Quality of Service (QoS) (Ericsson, 2024).

To address increasing traffic demand, 5G networks employ **small-cell deployment** as a complement to traditional macro base stations. Small cells improve network densification, expand coverage, reduce transmission distances, and increase spectrum reuse, thereby enhancing throughput and reducing latency in high-density urban areas (GSMA, 2025). However, large-scale small-cell deployment also introduces challenges relating to infrastructure costs, interference management, and network coordination.

Network slicing further distinguishes 5G from previous mobile generations by enabling multiple virtual networks to operate simultaneously on shared physical infrastructure. Each network slice can be optimized for specific applications with different latency, bandwidth, and reliability requirements. This capability supports diverse services ranging from enhanced mobile broadband to mission-critical industrial applications while improving overall network flexibility and resource utilization (Nokia, 2024).

Urban environments present unique challenges for wireless communication because of dense infrastructure, high-rise buildings, user mobility, and increasing device density. These conditions create multipath propagation, shadow fading, signal blockage, and frequent handovers that adversely affect communication performance. Studies indicate that although 5G significantly improves throughput and latency compared with 4G, maintaining consistent performance in dense metropolitan environments requires intelligent radio resource management, adaptive beamforming, and optimized cell planning (Huawei, 2025; Samsung Research, 2024).

Artificial intelligence (AI) and machine learning have become increasingly important in optimizing 5G network performance. AI-driven algorithms enable predictive traffic analysis, dynamic spectrum allocation, beam selection, fault detection, and automated network optimization, improving Quality of Service while reducing operational complexity (IEEE Communications Society, 2024). Edge computing further complements these capabilities by processing data closer to users, minimizing latency and supporting real-time applications such as autonomous vehicles, industrial automation, and smart healthcare.

Performance evaluation of 5G networks is commonly based on key indicators including throughput, latency, packet loss, spectral efficiency, signal-to-interference-plus-noise ratio (SINR), energy efficiency, reliability, and Quality of Service. Recent empirical studies consistently demonstrate that 5G outperforms previous wireless generations across these metrics, particularly when advanced technologies such as Massive MIMO, beamforming, and network slicing are jointly implemented (Cisco,

ISSN: 2971-7760 | VOL 7, ISS 1 | 06 AUGUST 2026
https://doi.org/10.5281/zenodo.21820030
NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

2024; Ericsson, 2024). Nevertheless, environmental conditions, user density, infrastructure deployment, and spectrum availability continue to influence network performance in practical urban deployments.

Recent studies reinforce these observations. Björnson and Sanguinetti (2023) reported significant improvements in spectral efficiency through Massive MIMO optimization, while Rappaport et al. (2022) demonstrated the importance of beamforming for overcoming mmWave propagation challenges. Ericsson (2024) observed that AI-assisted resource allocation substantially improves throughput and latency in dense urban environments. Similarly, **GSMA (2025)** emphasized that intelligent network densification and small-cell deployment are fundamental to supporting future smart-city applications. **Nokia (2024)** further highlighted network slicing as a critical mechanism for delivering differentiated services with varying Quality of Service requirements.

Despite these technological advances, several implementation challenges remain. High infrastructure costs, limited spectrum availability, dense urban interference, cybersecurity concerns, energy consumption, and the complexity of managing heterogeneous network architectures continue to constrain widespread deployment. Moreover, increasing dependence on software-defined networking, virtualization, and cloud-native architectures introduces additional security and operational challenges requiring robust network management strategies (Huawei, 2025; Cisco, 2024).

Although extensive research has examined individual 5G technologies, relatively few studies provide an integrated evaluation of how Massive MIMO, beamforming, mmWave communication, network slicing, artificial intelligence, and edge computing collectively influence communication performance within dense urban environments. This study addresses this gap by synthesizing recent advances in 5G technologies and evaluating their combined impact on throughput, latency, spectral efficiency, coverage, energy efficiency, and Quality of Service. The findings contribute to a better understanding of strategies for optimizing urban 5G deployments while providing practical guidance for future wireless communication systems.

METHODOLOGY

This study adopted a **qualitative conceptual research approach** to evaluate the performance of 5G communication systems in urban environments. The approach was selected because it enables the systematic synthesis of recent research findings, international standards, and industrial reports to examine the capabilities, challenges, and performance of emerging 5G technologies. Rather than collecting primary data, the study integrates existing empirical evidence to provide a comprehensive assessment of 5G network performance in dense urban settings.

ISSN: 2971-7760 | VOL 7, ISS 1 | 06 AUGUST 2026
https://doi.org/10.5281/zenodo.21820030
NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

A **systematic literature review** design was employed to identify, evaluate, and synthesize relevant publications on urban 5G communications. The review focused on peer-reviewed journal articles, conference proceedings, international standards, technical reports, and industrial white papers published between **2021 and 2025**. Major sources included IEEE Xplore, SpringerLink, ScienceDirect, Wiley Online Library, MDPI, ACM Digital Library, 3GPP, the International Telecommunication Union (ITU), Ericsson, Nokia, Huawei, Cisco, and GSMA. Priority was given to recent publications addressing Massive MIMO, millimeter-wave communication, beamforming, network slicing, edge computing, artificial intelligence, and smart-city deployments.

Relevant literature was selected based on three criteria: (i) direct relevance to 5G communication systems, (ii) emphasis on urban wireless network performance, and (iii) publication in reputable academic or industrial sources. Studies focusing exclusively on legacy mobile technologies or lacking sufficient technical relevance were excluded. This selection process ensured that the review reflected current developments in fifth-generation wireless communication technologies.

The analysis was organized around widely accepted **Key Performance Indicators (KPIs)** used to evaluate wireless communication systems. These indicators included **throughput, latency, spectral efficiency, Quality of Service (QoS), energy efficiency, coverage, signal-to-interference-plus-noise ratio (SINR), reliability, and network capacity**. Comparative analysis was subsequently employed to examine how enabling technologies such as Massive MIMO, beamforming, millimeter-wave communication, network slicing, and small-cell deployment contribute to improvements in these performance metrics under dense urban conditions.

The reviewed evidence was synthesized using **thematic analysis**, whereby related findings were grouped into common themes representing major technological components, deployment challenges, optimization techniques, and future research directions. This approach facilitated the identification of recurring patterns and enabled an integrated evaluation of the technological factors influencing urban 5G performance.

Table 1. Summary of Methodological Components

Methodological Component	Description
Research Approach	Qualitative conceptual research
Research Design	Systematic literature review
Data Source	Secondary data
Sources Reviewed	Journal articles, conference papers, standards, white papers, technical reports
Publication Period	2021–2025
Databases	IEEE Xplore, SpringerLink, ScienceDirect, ACM,

	Wiley, MDPI
Performance Metrics	Throughput, latency, QoS, SINR, spectral efficiency, coverage, energy efficiency
Analysis Technique	Comparative and thematic analysis
Outcome	Integrated evaluation of 5G performance in urban environments

The conceptual methodology provides a robust framework for synthesizing contemporary evidence on 5G communication technologies and evaluating their effectiveness in addressing the performance demands of modern urban environments. The findings offer practical insights for researchers, network operators, policymakers, and telecommunications engineers involved in designing and deploying next-generation wireless communication systems.

PERFORMANCE ANALYSIS AND DISCUSSION

Performance Challenges of 5G Networks in Urban Environments

Urban environments present one of the most demanding scenarios for fifth-generation (5G) communication systems because of dense populations, high-rise buildings, complex infrastructure, and massive mobile device connectivity. These conditions introduce propagation challenges such as multipath fading, shadowing, signal blockage, and frequent handovers, which can degrade network performance despite the advanced capabilities of 5G technologies (ITU, 2024). Furthermore, increasing traffic demand from smart city applications, autonomous vehicles, industrial IoT, and multimedia services places additional pressure on network resources, making efficient spectrum utilization and intelligent resource management essential.

The adoption of millimeter-wave (mmWave) frequencies significantly increases bandwidth availability but also introduces higher propagation losses and weaker penetration through buildings and obstacles. Consequently, maintaining reliable coverage requires dense deployment of small cells, adaptive beamforming, and intelligent mobility management (Ericsson, 2024). These challenges demonstrate that urban 5G performance depends not only on radio technologies but also on optimized network planning and infrastructure deployment.

Performance of Massive MIMO and Beamforming

Massive Multiple-Input Multiple-Output (Massive MIMO) remains one of the most influential technologies supporting 5G performance. By employing large antenna arrays, Massive MIMO enables simultaneous communication with multiple users, significantly improving spectral

ISSN: 2971-7760 | VOL 7, ISS 1 | 06 AUGUST 2026
https://doi.org/10.5281/zenodo.21820030
NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

efficiency, network capacity, and signal quality while reducing interference (Björnson & Sanguinetti, 2023).

Beamforming complements Massive MIMO by directing radio signals toward intended users instead of broadcasting energy uniformly. This focused transmission enhances received signal strength, extends coverage, and minimizes interference between neighboring users. Recent studies indicate that combining Massive MIMO with adaptive beamforming substantially improves throughput and network reliability in densely populated metropolitan environments (Huawei, 2025).

Millimeter-Wave Communication and Small-Cell Deployment

Millimeter-wave communication enables multi-gigabit data transmission by utilizing high-frequency spectrum resources unavailable to previous wireless generations. These frequencies provide exceptional bandwidth but experience significant attenuation caused by buildings, vegetation, rainfall, and human movement (Rappaport et al., 2022). Consequently, large-scale urban deployment requires dense small-cell infrastructure to maintain uninterrupted connectivity.

Small-cell architectures reduce transmission distances, improve frequency reuse, and increase overall network capacity. However, their deployment introduces additional challenges related to infrastructure costs, interference coordination, and backhaul connectivity. Effective integration of small cells with macro base stations therefore remains essential for achieving seamless urban coverage and consistent Quality of Service (GSMA, 2025).

Network Slicing and AI-Driven Network Optimization

Network slicing enables multiple virtual networks to coexist on a shared physical infrastructure, allowing operators to allocate resources according to specific application requirements. Services such as autonomous driving, industrial automation, smart healthcare, and enhanced mobile broadband can therefore operate independently while maintaining their respective Quality of Service requirements (Nokia, 2024).

Artificial Intelligence (AI) further enhances network performance by supporting predictive traffic management, intelligent beam selection, dynamic spectrum allocation, fault detection, and automated resource optimization. AI-assisted network management reduces congestion, minimizes latency, and improves service reliability under highly dynamic urban traffic conditions (IEEE Communications Society, 2024). The combination of AI, edge computing, and software-defined networking is expected to become increasingly important as urban communication networks continue to expand.

Comparative Performance Analysis

Recent comparative studies consistently demonstrate that 5G significantly outperforms previous mobile generations across major communication performance indicators. Improvements are particularly evident in throughput, latency, spectral efficiency, energy efficiency, and support for massive IoT connectivity. Nevertheless, network performance remains strongly influenced by deployment density, propagation conditions, spectrum availability, and intelligent resource management.

Table 2. Comparative Performance of 4G and 5G Communication Systems

Performance Metric	**4G LTE**	**5G**
Peak Data Rate	Up to 1 Gbps	Up to 20 Gbps
User Throughput	Moderate	Very High
Latency	20–50 ms	1–10 ms
Spectral Efficiency	Moderate	High
Massive IoT Support	Limited	Excellent
Beamforming	Limited	Advanced
Massive MIMO	Limited	Extensive
Network Slicing	Not Supported	Fully Supported
Energy Efficiency	Moderate	High
Smart City Support	Moderate	Excellent

Source: Developed by the Author (2026), synthesized from ITU (2024), Ericsson (2024), Nokia (2024), and GSMA (2025).

ISSN: 2971-7760 | VOL 7, ISS 1 | 06 AUGUST 2026
https://doi.org/10.5281/zenodo.21820030
NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

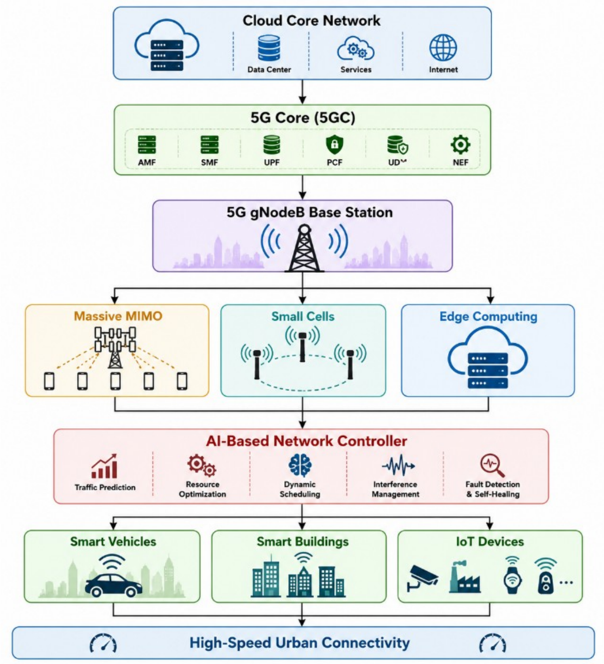

Figure 2. 5G urban communication architecture supporting intelligent wireless services.

Source: Developed by the Author (2026).

ISSN: 2971-7760 | VOL 7, ISS 1 | 06 AUGUST 2026
https://doi.org/10.5281/zenodo.21820030
NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

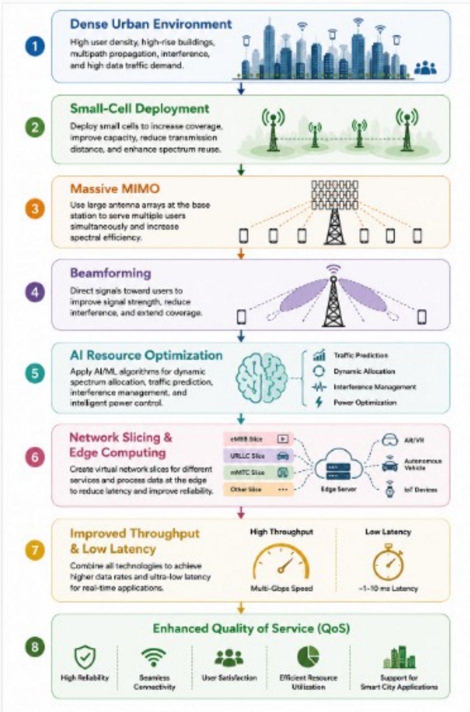

Figure 3. Performance enhancement framework for optimizing 5G communication systems in urban environments.

Source: Developed by the Author (2026).

ISSN: 2971-7760 | VOL 7, ISS 1 | 06 AUGUST 2026
https://doi.org/10.5281/zenodo.21820030
NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

DISCUSSION

The analysis confirms that no single technology is sufficient to achieve optimal urban 5G performance. Instead, improvements result from the combined deployment of Massive MIMO, beamforming, millimeter-wave communication, network slicing, artificial intelligence, and edge computing. Their integration enhances throughput, minimizes latency, improves spectral efficiency, and supports reliable connectivity for smart-city applications. However, infrastructure investment, spectrum management, cybersecurity, and energy efficiency remain important challenges that must be addressed to maximize the benefits of 5G deployment. These findings provide practical guidance for future network planning and establish a foundation for the evolution toward Beyond-5G and sixth-generation (6G) communication systems.

Future Perspectives

The evolution of fifth-generation (5G) communication is expected to accelerate the development of intelligent and autonomous wireless networks capable of supporting increasingly complex urban digital ecosystems. Emerging technologies such as **Artificial Intelligence (AI)**, **Machine Learning (ML)**, **edge computing**, **Open Radio Access Networks (Open RAN)**, **Intelligent Reflecting Surfaces (IRS)**, and **digital twins** will play a significant role in improving network efficiency, reducing latency, and enhancing resource allocation. These innovations will enable communication systems to adapt dynamically to traffic demands while supporting next-generation applications including autonomous transportation, smart healthcare, industrial automation, and immersive extended reality services (ITU, 2024; Ericsson, 2024).

Future urban communication networks are also expected to evolve toward **Beyond-5G (B5G)** and **6G** technologies, integrating terrestrial, aerial, and satellite communication infrastructures into a unified intelligent network. Such convergence will improve ubiquitous connectivity, energy efficiency, and service reliability while supporting sustainable smart-city development. Future research should therefore focus on AI-native network management, green communication technologies, cybersecurity for software-defined networks, and intelligent spectrum management to maximize the potential of next-generation wireless communication systems.

CONCLUSION

This study examined the performance of **5G communication systems in urban environments** by reviewing the technologies and factors influencing network efficiency. The analysis demonstrated that **Massive MIMO**, **beamforming**, **millimeter-wave communication**, **small-cell deployment**, **network slicing**, and **AI-driven optimization** significantly enhance throughput, reduce latency, improve spectral efficiency, and support massive device connectivity. However, challenges including signal attenuation, infrastructure costs, interference management, and cybersecurity remain barriers to optimal deployment. The study concludes that effective urban 5G performance depends on the integration of advanced communication technologies with intelligent network planning and resource management. These findings provide practical guidance for network operators, policymakers, and researchers seeking to deploy resilient, high-capacity wireless communication systems that support future smart-city applications.

RECOMMENDATIONS

Based on the findings, telecommunications operators should expand **small-cell infrastructure**, implement **Massive MIMO** and **adaptive beamforming**, and adopt **AI-enabled network optimization** to improve urban network performance. Governments should encourage investment in digital infrastructure and spectrum management policies that facilitate efficient 5G deployment while supporting smart-city initiatives. Furthermore, network designers should integrate **edge computing**, **network slicing**, and robust **cybersecurity mechanisms** to improve reliability, Quality of Service (QoS), and resilience. Future studies should empirically evaluate large-scale urban deployments and investigate the integration of **Beyond-5G** and **6G** technologies with intelligent wireless communication systems.

ACKNOWLEDGEMENTS

Tertiary Education Trust Fund (TETFUND) is the sole sponsor of this research work

REFERENCES

3rd Generation Partnership Project. (2024). *The 3GPP specifications for 5G New Radio (Release 18).* https://www.3gpp.org

Björnson, E., & Sanguinetti, L. (2023). Making massive MIMO a reality: Opportunities and challenges. *IEEE Communications Magazine, 61*(4), 126–132.

Cisco. (2024). *Cisco annual internet report: Global network trends and forecasts*. Cisco Systems.

Ericsson. (2024). *Ericsson mobility report: June 2024*. Ericsson.

GSMA. (2025). *The mobile economy 2025*. GSM Association.

ISSN: 2971-7760 | VOL 7, ISS 1 | 06 AUGUST 2026
https://doi.org/10.5281/zenodo.21820030
NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

Huawei Technologies. (2025). *5G network evolution and intelligent wireless communications white paper*. Huawei.

International Telecommunication Union. (2024). *IMT-2020: Vision, requirements and future development of 5G systems*. ITU.

Li, X., Wang, Y., Zhang, H., & Chen, Z. (2023). Artificial intelligence-enabled resource allocation in fifth-generation wireless networks: A review. *IEEE Access, 11*, 54782–54801.

Nokia. (2024). *Network slicing and edge computing for 5G and beyond*. Nokia Bell Labs.

Parastar, P., Lutu, A., Alay, Ö., Caso, G., & Perino, D. (2023). Spotlight on 5G: Performance, device evolution and challenges from a mobile operator perspective. In *Proceedings of the IEEE INFOCOM 2023 – IEEE Conference on Computer Communications*.

Rappaport, T. S., Xing, Y., MacCartney, G. R., Molisch, A. F., Mellios, E., & Zhang, J. (2022). Overview of millimeter-wave communications for fifth-generation (5G) wireless networks. *IEEE Transactions on Antennas and Propagation, 70*(6), 4103–4123.

Saad, W., Bennis, M., & Chen, M. (2022). A vision of 6G wireless systems: Applications, trends, technologies, and open research problems. *IEEE Network, 36*(3), 134–142.

Samsung Research. (2024). *Advanced radio technologies for future 5G and beyond wireless networks*. Samsung Electronics.

Shafi, M., Molisch, A. F., Smith, P. J., Haustein, T., Zhu, P., Silva, P., Tufvesson, F., Benjebbour, A., & Wunder, G. (2022). 5G: A tutorial overview of standards, trials, challenges, deployment, and practice. *IEEE Journal on Selected Areas in Communications, 40*(7), 2025–2054.

Wang, C.-X., You, X., Gao, X., Zhu, X., Li, Z., Zhang, C., Huang, Y., Chen, Y., Haas, H., Thompson, J. S., Larsson, E. G., Di Renzo, M., Tong, W., Zhu, P., Shen, X., Poor, H. V., & Hanzo, L. (2023). On the road to 6G: Visions, requirements, key technologies, and testbeds. *IEEE Communications Surveys & Tutorials, 25*(2), 905–974.

Yazar, A., & Arslan, H. (2022). Flexible radio resource management techniques for fifth-generation and beyond wireless communication systems. *IEEE Wireless Communications, 29*(3), 84–91.

Zhang, J., Ge, X., Li, Q., Guizani, M., & Zhang, Y. (2023). Artificial intelligence-driven optimization for next-generation wireless

ISSN: 2971-7760 | VOL 7, ISS 1 | 06 AUGUST 2026
https://doi.org/10.5281/zenodo.21820030
NASARAWA STATE UNIVERSITY, KEFFI, NIGERIA

communication networks. *IEEE Communications Surveys & Tutorials, 25*(4), 2548–2581.