World Journal of Advanced Engineering Technology and Sciences
eISSN: 2582-8266
Cross Ref DOI: 10.30574/wjaets
Journal homepage: https://wjaets.com/

(REVIEW ARTICLE)

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Advancing beyond 5G: A review of network densification strategies

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World Journal of Advanced Engineering Technology and Sciences, 2025, 15(01), 774-779

Publication history: Received on 26 January 2025; revised on 01 April 2025; accepted on 05 April 2025

Article DOI: https://doi.org/10.30574/wjaets.2025.15.1.0185

Abstract

The advent of fifth-generation (5G) mobile technology represents a transformative leap in telecommunications, promising unprecedented speeds, reduced latency, and enhanced connectivity. In Nigeria, the deployment of 5G is crucial for meeting the surging demand for data driven by digital services, social media, and emerging technologies. This review paper, titled "Advancing Beyond 5G: A Review of Network Densification Strategies," explores the current state of 5G implementation in Nigeria, focusing on the roles of major Mobile Network Operators (MNOs) such as MTN, Airtel, Globacom, and 9mobile. It examines the spectrum resources allocated to these operators and the challenges they face in infrastructure development and regulatory compliance. The paper delves into the concept of network densification as a vital strategy for enhancing network capacity and performance, particularly in urban areas. It discusses various techniques, including the deployment of small cells, massive MIMO, and heterogeneous networks, while addressing the economic and regulatory hurdles that may impede progress. Furthermore, the review highlights successful case studies from both local and international contexts, providing insights into best practices for effective densification. Finally, the paper outlines future directions for telecommunications in Nigeria, emphasizing the need for innovative approaches and collaboration among stakeholders to ensure sustainable growth beyond 5G. By synthesizing current knowledge and identifying gaps in the literature, this review aims to contribute to the ongoing discourse on advancing mobile communication networks in Nigeria and beyond.

Keywords: 5G Technology; Network Densification; Mobile Network Operators (MNOs); Spectrum; millimetre Wave

1. Introduction

Fifth-generation (5G) technology represents a significant advancement in mobile telecommunications, designed to meet the increasing demand for high-speed data and connectivity. Unlike its predecessors, 5G offers enhanced capabilities, including ultra-low latency, higher data rates, and the ability to connect a vast number of devices simultaneously [1], [2]. As of June 2021, numerous countries, including Nigeria, began rolling out 5G networks, with major Mobile Network Operators (MNOs) such as MTN leading the charge by acquiring 100MHz wide spectrum in the 3.5 GHz band, which is crucial for deploying 5G services [3]. The rollout of 5G technology has brought transformative changes across multiple industries, including healthcare, transportation, and entertainment. It facilitates the development of cutting-edge applications like smart cities, autonomous vehicles, and the Internet of Things (IoT), driving innovation and enhancing connectivity in unique ways.

2. Significance of Network Densification

As the demand for mobile data continues to surge, network densification has emerged as a critical strategy for enhancing the capacity and performance of 5G networks. Network densification involves increasing the number of base stations and small cells within a given area to improve coverage and reduce congestion [4]. This approach is particularly vital in urban environments, where high user density can lead to significant challenges in maintaining service quality. By

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deploying advanced technologies such as Multiple-Input Multiple Output (MIMO) and utilizing existing infrastructure creatively, MNOs can optimize their networks to support the anticipated exponential growth in traffic volume. Furthermore, effective network densification not only enhances user experience but also plays a pivotal role in addressing the infrastructural deficits and regulatory challenges faced in regions like Nigeria, ultimately paving the way for a robust and sustainable 5G ecosystem,

3. Key Mobile Network Operators (MNOs) and Their Roles

Four MNOS dominate the mobile communication market, accounting for nearly all telecommunication subscribers in Nigeria. They include MTN, 9mobile, Airtel, and Globacom. Second generation services began in 2001, with ECONET Wireless (now known as airtel) and MTN Nigeria being the first MNOs to gain full GSM operational licenses**.** Meanwhile, Globacom started operation in 2003 and 9mobile got launched in 2008 [5]. All of the MNOs listed above now have 4G operational licenses. However, MTN and a new telecommunication company MAFAB purchased 3.5GHZ spectrum for the 5G operations launched into full action [6]. According to the news published on the Nigerian Communication Commissions (NCC), NCC issued final letter of awards for roll out after the federal government had approved commencement. The deadline for the 5G licensed MNOs in Nigeria to start was till August 2022 [7], [6].The Table 1 below shows the summary of the MNOs, their deployed mobile telecommunication networks, frequency bands, and resources.

Table 1 Summary of MNOs in Nigeria and their spectrum resources

Mobile Network Operator	Deployed Mobile Communications	Frequency Band	Spectrum Resources (MHz)	Expiry Dates	Services
9Mobile	2G GSM	900MHz	TX:935-940 RX: 890-895	Valid until 2025	Data, Call, Roaming, SIM
	3G UMTS	2100MHz	TX: 2130-2140 RX: 1940-1950	Valid until 2025	Data, Voice, Roaming, SIM
	4G LTE	1800MHz	TX: 1865-1880 RX: 1770-1785	Valid until 2025	Data, Voice, Roaming, SIM
Airtel	2G GSM	900MHz	TX:925-935 RX: 880-890	Valid until 2025	Data, Call, Roaming, SIM
		1800MHz	TX: 1850-1865 RX: 1755-1770	Valid until 2025	
	3G UMTS	2100MHz	TX: 2140-2150 RX: 1950-1960	Valid until 2025	Data, Voice, Roaming, SIM
	4G LTE	2600MHz	TX: 2500-2520 RX: 2620-2640	Valid until 2030	Data, Voice, Roaming, SIM
GLO MAFAB communications limited	2G GSM	900MHz	TX: 945-950 RX: 900-905	Valid until 2025	Data, Call, Roaming, SIM
		1800MHz	TX: 1820-1835 RX: 1725-1740	Valid until 2025	
	3G UMTS	2100MHz	TX: 2120-2130 RX: 1930-1940	Expired	
	4G LTE	700MHz	TX: 723-733 RX: 778-788	Valid until 2025	Data, Voice, Roaming, SIM
	5G	3.5GHz	TX: 3700-3800	Valid until 2030	Data, Voice, Cloud Hosting
MTN	2G GSM	900MHz	TX: 950-955 RX: 905-910	Expired	Data, Call, Roaming, SIM

	2G GSM	1800MHz	TX: 1835-1850 RX: 1740-1755	Expired	Data, Call, Roaming, SIM
	3G UMTS	2100MHz	TX: 2110-2120 RX: 1920-1930	Valid until 2025	Data, Call, Roaming, SIM
	4G LTE	2600MHz	TX: 2520-2550 RX: 2640-2670	Valid until 2030	Data, Voice, Roaming, SIM
	4G LTE	800MHz	TX: 832-842 RX: 791-801	Valid until 2025	Data, Voice, Roaming, SIM
	5G	3.5GHz	TX: 3500-3600	Valid until 2035	Data, Voice, Roaming, SIM

3.1. Challenges Faced in Network Deployment

Despite the progress made in deploying mobile networks, several challenges hinder the effective rollout of 5G services in Nigeria. One of the primary issues is the inadequate infrastructure, which includes a lack of reliable power supply, poor road networks, and insufficient backhaul connectivity [8]. These infrastructural deficits complicate the installation and maintenance of base transceiver stations (BTS) and other essential components of mobile networks. Additionally, regulatory hurdles pose significant challenges to network deployment. The complex licensing processes and the need for multiple approvals can delay the rollout of new technologies [3]. Furthermore, the economic landscape in Nigeria, characterized by low average revenues per user, presents a barrier to investment in network expansion and densification [8]. Interference management and the need for effective spectrum utilization are also critical challenges. As network densification increases, the potential for interference among densely deployed cells rises, necessitating advanced strategies for interference mitigation [9].

3.2. Strategies for Network Densification in Nigeria: Integration of Small Cells and Microcells

One of the most effective strategies for network densification in Nigeria is the integration of small cells and microcells into the existing mobile network infrastructure. Small cells are low-power radio access nodes that can be deployed in high-density areas to enhance coverage and capacity. They operate on licensed and unlicensed spectrum and can significantly improve user experience by providing better signal quality and higher data rates. The deployment of small cells is particularly beneficial in urban environments where traditional macro cells may struggle to meet the increasing demand for mobile data services. Microcells, which are slightly larger than small cells, can also be utilized to fill coverage gaps and improve network performance in areas with high user density [11]. By strategically placing these cells in locations such as shopping malls, stadiums, and public transport hubs, MNOs can effectively manage traffic loads and enhance overall network efficiency [8].

3.3. Infrastructure Sharing and Collaborative Approaches

Infrastructure sharing is another critical strategy for network densification in Nigeria. By allowing multiple MNOs to share physical infrastructure such as towers, antennas, and backhaul connections, operators can reduce deployment costs and accelerate the rollout of new technologies. This collaborative approach not only minimizes redundancy but also optimizes resource utilization, making it a cost-effective solution for expanding network coverage [8]. In Nigeria, where the economic landscape poses challenges for individual MNOs, infrastructure sharing can facilitate faster deployment of 5G networks. Collaborative initiatives among operators can lead to improved service delivery and a more robust telecommunications ecosystem [10]. Additionally, partnerships with local governments and private entities can further enhance infrastructure development and maintenance.

3.4. Utilization of Advanced Technologies (e.g., mmWave, Het-Nets)

The utilization of advanced technologies such as millimeter wave (mmWave) and heterogeneous networks (Het-Nets) is essential for achieving effective network densification in Nigeria. mmWave technology offers high-frequency bands that can support extremely high data rates and capacity, making it ideal for densely populated urban areas [13]. However, the deployment of mmWave requires careful planning due to its limited range and susceptibility to physical obstructions. Heterogeneous networks, which combine different types of cells (macro, micro, and small cells), can also enhance network performance by providing seamless connectivity and load balancing across various network layers. This approach allows MNOs to optimize their resources and deliver a consistent user experience, even in challenging environments.

4. Challenges and Opportunities

4.1. Infrastructural Deficits and Economic Considerations

Nigeria's telecommunications sector faces significant infrastructural deficits that hinder the effective deployment of mobile networks. Issues such as unreliable power supply, inadequate road networks, and insufficient backhaul connectivity pose challenges for MNOs seeking to expand their services [8]. These infrastructural limitations not only increase operational costs but also delay the rollout of new technologies, particularly in rural and underserved areas. Economic considerations further complicate the situation. The low average revenue per user in Nigeria makes it challenging for MNOs to justify the high costs associated with network densification and infrastructure development. However, addressing these deficits presents an opportunity for innovation in financing models, such as public-private partnerships, which can facilitate investment in critical infrastructure and improve service delivery.

4.2. Regulatory Hurdles and Policy Recommendations

Regulatory hurdles are another significant challenge in the deployment of mobile networks in Nigeria. The complex licensing processes and the need for multiple approvals can slow down the rollout of new technologies [8], including 5G. Additionally, inconsistent regulatory frameworks can create uncertainty for MNOs, deterring investment in network expansion.

To overcome these challenges, it is essential to streamline regulatory processes and establish clear policies that support network densification efforts. Policymakers should consider implementing a more flexible regulatory framework that encourages innovation and collaboration among stakeholders. Recommendations include simplifying the licensing process, promoting infrastructure sharing, and providing incentives for MNOs to invest in underserved areas

4.3. Potential for Innovation and Multi-Stakeholder Collaboration

Despite the challenges, there is significant potential for innovation and multi-stakeholder collaboration in Nigeria's telecommunications sector. Engaging various stakeholders, including government agencies, MNOs, technology providers, and local communities, can lead to more effective solutions for network densification. Collaborative initiatives can facilitate knowledge sharing, resource pooling, and the development of innovative technologies tailored to local needs. Furthermore, using emerging technologies such as artificial intelligence and machine learning can enhance network planning and optimization, enabling MNOs to better manage traffic loads and improve service quality [8]. By nurturing a culture of innovation and collaboration, Nigeria can position itself as a leader in mobile telecommunications in Africa.

5. Case Studies and Best Practices

5.1. Proposed Densification Initiatives in Urban Areas

Several proposed densification initiatives in urban areas around the world provide valuable insights for Nigeria. For instance, cities like Taiz and Detroit have effectively proposed systems that could work by assessing the infrastructural demands of integrating 5G technology and Het-Nets and mm-Wave [13], [15]. These technologies would make existing networks to enhance coverage and capacity in densely populated areas. These cities papers suggest that strategic placement of small cells in high-traffic locations, such as public transport hubs and commercial districts, can significantly improve user experience and network performance. In Nigeria, similar approaches can be adopted, focusing on urban centers where demand for mobile data is highest. By learning from these successful proposed studies, Nigerian MNOs can implement targeted densification strategies that address local challenges and optimize resource utilization.

5.2. Lessons Learned from Other Regions

Examining lessons learned from other regions can provide valuable guidance for Nigeria's network densification efforts. For example, the experience of countries in Europe and Asia highlights the importance of regulatory support and infrastructure sharing in facilitating rapid network deployment. These regions have successfully implemented policies that encourage collaboration among MNOs, leading to improved service delivery and reduced costs. Additionally, the use of advanced technologies, such as mmWave and Het-Nets [15], will prove effective in enhancing network capacity and performance in urban environments. By adopting similar strategies and tailoring them to the unique context of Nigeria, MNOs can overcome existing challenges and capitalize on opportunities for growth and innovation.

6. Future Directions and Research Gaps

6.1. Emerging Trends in Network Densification

As the demand for mobile data continues to surge, emerging trends in network densification are shaping the future of telecommunications. One significant trend is the increasing adoption of small cells and distributed antenna systems (DAS) to enhance coverage and capacity in urban environments. These technologies allow for more efficient use of spectrum and can be deployed rapidly to meet growing user demands [14].

Additionally, the integration of advanced technologies such as Massive MIMO (Multiple Input Multiple Output) and beamforming is becoming more prevalent. These technologies improve spectral efficiency and enable better handling of interference, which is crucial in densely populated areas. The shift towards network virtualization and software-defined networking (SDN) is also noteworthy, as it allows for more flexible and scalable network management, facilitating quicker responses to changing traffic patterns.

In the context of 5G and beyond, the concept of ultra-dense networks (UDN) is gaining traction [12]. UDNs influence a high density of small cells to provide enhanced user experiences and meet the anticipated exponential growth in data traffic. This trend emphasizes the need for innovative approaches to network planning and deployment, particularly in urban settings where traditional macro-cell architectures may fall short.

6.2. Areas for Further Research in the Nigerian Context

While significant progress has been made in understanding network densification, there remain critical areas for further research, particularly within the Nigerian context. One key area is the development of localized models that accurately reflect the unique challenges and characteristics of Nigeria's telecommunications landscape. Existing models often fail to account for local factors such as infrastructure deficits, regulatory complexities, and socio-economic conditions [8]. Another important research area is the exploration of innovative financing models that can support network densification efforts. Given the economic constraints faced by MNOs in Nigeria, research into public-private partnerships, community-based funding, and alternative investment strategies could provide valuable insights.

7. Conclusion

7.1. Summary of Key Findings

This study has highlighted the critical role of network densification in enhancing mobile network performance in Nigeria. Key findings indicate that while significant challenges exist such as infrastructural deficits, regulatory hurdles, and economic constraints there are also numerous opportunities for innovation and collaboration. Proposed densification initiatives from other regions provide valuable lessons that can be adapted to the Nigerian context, emphasizing the importance of strategic planning and stakeholder engagement. The research has also identified emerging trends in network densification, including the adoption of small cells, advanced antenna technologies, and the shift towards ultra-dense networks. These trends underscore the need for ongoing research and development to address the unique challenges faced by Nigeria's telecommunications sector.

7.2. Implications for the Future of Mobile Networks in Nigeria

The implications of these findings for the future of mobile networks in Nigeria are profound. As the demand for mobile data continues to grow, effective network densification strategies will be essential for ensuring that MNOs can meet user expectations and remain competitive. Policymakers must prioritize the development of a supportive regulatory environment that encourages investment and innovation in telecommunications infrastructure. Moreover, fostering collaboration among stakeholders including government agencies, MNOs, and technology providers will be crucial for overcoming existing challenges and leveraging opportunities for growth. By addressing research gaps and focusing on localized solutions, Nigeria can enhance its telecommunications landscape and position itself as a leader in mobile communications in Africa. In conclusion, the future of mobile networks in Nigeria hinges on the successful implementation of network densification strategies that are tailored to the unique context of the country. By embracing innovation and collaboration, Nigeria can unlock the full potential of its telecommunications sector and improve service delivery for its growing population

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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