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Energy and Performance Analysis of a Zero-Carbon 5G-Advanced Site Deployment in a Live Network Environment

Noaman Taufiq[1], and Muhammad Arif Saeed[2]
Saudi Telecom Company

***Abstract*—The rapid expansion of multi-band LTE and 5G networks has significantly increased site complexity, equipment footprint, and energy consumption. The introduction of additional low-band and mid-band spectrum layers improves network capacity and coverage but creates challenges related to power consumption, site rental costs, and environmental sustainability. This paper presents the deployment and evaluation of a Zero-Carbon 5G-Advanced (5G-A) site architecture in a live commercial network. The proposed solution consolidates multiple radio units into an integrated GigaGreen architecture while maintaining network performance and service continuity. Performance assessment was conducted using OSS statistics, LTE and NR key performance indicators (KPIs), and extensive drive test measurements. Results show a reduction of approximately 32% in daily power consumption, equivalent to 27.66 kWh per day per site, while maintaining stable LTE and 5G performance metrics. The findings demonstrate that the Zero-Carbon 5G-A architecture can significantly improve energy efficiency without negatively affecting user experience, making it a viable solution for sustainable future mobile networks.**

***Index Terms*—5G-Advanced (5G-A), Zero-Carbon Network, Energy-Efficient Radio Access Network, Green Telecommunications, GigaGreen, Artificial Intelligence-Based Energy Saving, Network Modernization, Sustainable Wireless Communications.**

I. INTRODUCTION

The evolution of mobile networks from 2G to 5G has resulted in a continuous increase in spectrum utilization, network capacity, and service complexity. Modern cellular sites are required to support multiple technologies and frequency bands simultaneously, including low-band LTE, mid-band LTE, and 5G New Radio (NR). While these deployments improve network performance and user experience, they also increase equipment footprint area (EPA), site rental costs, and power consumption.

With the introduction of additional 5G spectrum layers, network operators face growing operational expenditure associated with energy usage and infrastructure expansion. Energy efficiency has therefore become a key objective in the development of future 5G-Advanced (5G-A) networks. Sustainable network architectures capable of reducing power consumption while maintaining service quality are essential for achieving long-term operational and environmental goals.

To address these challenges, a Zero-Carbon 5G-A site architecture known as GigaGreen was introduced and evaluated in a live commercial network. The solution integrates multiple frequency bands into a consolidated radio architecture, reducing hardware requirements and improving energy efficiency. This paper presents the deployment methodology, performance evaluation, and operational benefits of the proposed architecture using network KPIs, power consumption measurements, and drive test validation.

TABLE I: Power Consumption Reduction

Metric	Before	After
Power Consumption	84 kWh/day	56 kWh/day
Reduction	32%	
Energy Saving	27.66 kWh/day/site	

II. ZERO-CARBON 5G SITE ARCHITECTURE

The rapid evolution of mobile networks has led to the deployment of multiple LTE and 5G frequency bands to satisfy increasing traffic demands and provide enhanced user experiences. However, the addition of new spectrum layers often requires the installation of dedicated radio units, resulting in increased site complexity, higher power consumption, larger equipment footprint areas (EPA), and elevated operational expenditure (OPEX). As network operators continue expanding 5G coverage and capacity, achieving sustainable network growth has become a major industry challenge.

To address these challenges, a Zero-Carbon 5G-Advanced (5G-A) architecture based on Huawei's GigaGreen solution was introduced. The primary objective of this architecture is to reduce site energy consumption while maintaining network performance and service quality. The solution achieves this by consolidating multiple radio technologies and frequency bands into a highly integrated multi-band radio platform, thereby simplifying the overall site architecture and improving operational efficiency.

In the conventional deployment model, separate radio units were installed for different frequency bands, including 700 MHz, 900 MHz, 1800 MHz, and 2100 MHz. Each radio required independent power resources, cabling, cooling, and maintenance support, contributing significantly to site power consumption and equipment footprint. The proposed GigaGreen architecture replaces these legacy single-band radios with advanced multi-band radio units capable of simultaneously supporting multiple LTE and NR frequency layers within a single hardware platform.

One of the most significant advantages of the proposed architecture is the reduction in hardware complexity. As illustrated in the deployment design, the total number of radio equipment boxes was reduced from seventeen to nine through

TABLE II: LTE KPI Comparison

Metric	Before	After
DL PRB Utilization	22%	24.37%
UL PRB Utilization	20.4%	20.6%
DL Throughput	16.94 Mbps	16.50 Mbps
UL Throughput	1.64 Mbps	1.63 Mbps
Average Users	210	236

hardware consolidation. This reduction decreases site space requirements, simplifies installation and maintenance activities, and lowers the overall power demand of the radio access network. Furthermore, fewer hardware components translate into lower cooling requirements and improved site reliability.

The architecture also incorporates advanced artificial intelligence (AI)-based energy-saving mechanisms designed to optimize power consumption dynamically according to network traffic conditions. A key feature is Huawei's Zero-Bit Zero-Watt technology, which intelligently identifies periods of low network utilization and places unused radio resources into ultra-low-power states. Unlike traditional power-saving methods that may affect network availability, this technology enables energy reduction without compromising user experience or network accessibility. When traffic demand increases, radio resources are automatically reactivated to ensure seamless service continuity.

Another important benefit of the integrated architecture is its ability to maintain full compatibility with existing network infrastructure. The deployment supports both LTE and 5G NR services while leveraging the existing baseband processing units and transport network architecture. As a result, operators can implement the Zero-Carbon solution without requiring extensive modifications to the core network or transmission infrastructure. This minimizes deployment costs and accelerates network modernization efforts.

From an operational perspective, the consolidated architecture contributes directly to sustainability objectives by reducing overall site energy consumption and carbon emissions. By combining multi-band radio integration, intelligent power management, and infrastructure reuse, the Zero-Carbon 5G-A architecture provides a practical framework for building environmentally sustainable mobile networks. The solution enables operators to support future traffic growth while simultaneously improving energy efficiency and reducing operational costs.

Overall, the proposed GigaGreen-based Zero-Carbon 5G-A architecture demonstrates that significant reductions in power consumption can be achieved without compromising network performance. The combination of radio consolidation, AI-driven energy optimization, and infrastructure compatibility makes it a highly effective solution for next-generation green mobile network deployments.

III. ENERGY SAVING ANALYSIS

Energy efficiency has become one of the primary objectives in modern mobile network deployments due to the rapid increase in network traffic, spectrum utilization, and equipment density. The addition of multiple LTE and 5G layers significantly increases the power consumption of radio access networks, resulting in higher operational expenditure (OPEX) and carbon emissions. Therefore, evaluating the energy-saving capability of the proposed Zero-Carbon 5G-A architecture is essential to determine its operational and environmental benefits.

The power consumption reduction achieved by the GigaGreen solution was evaluated by comparing the average site power consumption before and after deployment. Measurements were collected through the Operations Support System (OSS) over identical observation periods to ensure a fair comparison. The energy-saving percentage was calculated using the difference between the pre-deployment and post-deployment power consumption values.

The total energy saving can be expressed as:

$$E_{saving} = P_{before} - P_{after} \tag{1}$$

where:

- E_{saving} represents the power reduction achieved by the optimized site architecture.
- P_{before} represents the average power consumption before deployment.
- P_{after} represents the average power consumption after deployment.

To quantify the improvement, the percentage reduction in power consumption is calculated as:

$$Saving(\frac{P_{before} - P_{after}}{P_{before}} \times 100 \tag{2}$$

Using the measured OSS data, the average daily energy saving was observed to be approximately 27.66 kWh per site, corresponding to a power reduction of nearly 32

The long-term financial impact of energy optimization can be estimated using the following equation:

$$Costsaving$$

E$_{saving} \times C_{elec} \times 365 \times N(3)$
where:

- $Cost_{saving}$ is the accumulated monetary saving.
- E_{saving} is the daily energy saving (kWh/day).
- C_{elec} is the electricity cost per kWh.
- N is the number of operational years.

Similarly, the annual energy saving can be calculated as:

$$Annual\ Energy\ Saving$$

E$_{saving} \times 365(4)$
For the evaluated site, the measured energy reduction of 27.66 kWh/day corresponds to an annual energy saving of approximately 10,096 kWh per site. When extrapolated across a nationwide network footprint consisting of thousands of sites, the cumulative reduction in energy consumption can result in substantial operational savings and significant reductions in carbon emissions.

The results demonstrate that the proposed Zero-Carbon 5G-A architecture successfully reduces energy consumption while maintaining stable LTE and NR performance. Therefore, the solution provides an effective approach for achieving sustainable network growth and supporting future green communication initiatives.

The total energy saving can be estimated as

$$E_{saving} = P_{before} - P_{after} \tag{5}$$

where:

- P_{before} = Power consumption before deployment
- P_{after} = Power consumption after deployment

The percentage reduction is calculated as

$$Saving(\%) = \frac{P_{before} - P_{after}}{P_{before}} \times 100 \tag{6}$$

IV. LTE KPI ANALYSIS

To evaluate the impact of the Zero-Carbon 5G-A architecture on existing LTE services, a comprehensive analysis of LTE key performance indicators (KPIs) was conducted before and after deployment. The objective of this assessment was to verify that the radio consolidation and hardware modernization process did not negatively affect network performance or user experience. Key LTE performance indicators including downlink throughput, uplink throughput, PRB utilization, and average connected users were analyzed using OSS measurements collected over comparable observation periods.

The LTE KPI comparison is summarized in Table II. The results indicate that LTE network performance remained stable following the implementation of the energy-efficient site architecture. Downlink PRB utilization increased slightly from 22

Although a minor decrease in average downlink throughput was observed, from 16.94 Mbps to 16.50 Mbps, the difference is negligible and does not indicate any degradation in user experience. Similarly, uplink throughput remained virtually unchanged, decreasing only from 1.64 Mbps to 1.63 Mbps. The stability of throughput performance demonstrates that the consolidation of multiple radio units into the integrated GigaGreen architecture successfully preserved LTE service quality while reducing energy consumption.

Furthermore, the average number of connected LTE users increased from 210 to 236 users after deployment, indicating sustained network accessibility and user retention. The increase in user count, combined with stable throughput and resource utilization metrics, confirms that the optimized architecture continued to support network demand efficiently without introducing congestion or capacity limitations.

Overall, the LTE KPI analysis demonstrates that the proposed Zero-Carbon 5G-A solution achieved significant energy savings while maintaining stable LTE network performance. The results confirm that the hardware transformation and radio consolidation process can be implemented without compromising coverage, capacity, or user experience, making it a practical approach for future energy-efficient mobile network deployments.

TABLE III: NR KPI Comparison

Metric	Before	After
DL PRB Utilization	10.37%	9.76%
UL PRB Utilization	16.3%	15.93%
Latency	2.96 ms	2.94 ms
DL Throughput	128.14 Mbps	128.41 Mbps
Users	35	35

V. NR KPI ANALYSIS

The performance of the 5G New Radio (NR) network was evaluated before and after the deployment of the Zero-Carbon 5G-A architecture to verify that the proposed energy-efficient solution did not negatively impact network quality or user experience. Key performance indicators including downlink PRB utilization, uplink PRB utilization, latency, throughput, and connected users were analyzed using OSS data collected over comparable observation periods.

The comparison of the major NR KPIs is presented in Table III. The results demonstrate that the implementation of the GigaGreen architecture maintained stable 5G network performance while significantly reducing site energy consumption. Downlink PRB utilization decreased slightly from 10.37% to 9.76%, while uplink PRB utilization reduced from 16.3% to 15.93%. These minor variations indicate that radio resources continued to be utilized efficiently after the hardware consolidation process and that no additional network congestion was introduced.

Latency performance remained highly stable following deployment. As shown in Table III, average NR latency improved marginally from 2.96 ms to 2.94 ms. Although the improvement is small, it confirms that the optimization process did not introduce additional delays or processing overhead within the radio access network. Maintaining low latency is critical for enhanced mobile broadband services and future 5G applications requiring real-time communication.

Throughput performance also remained consistent after deployment. The average NR downlink throughput increased slightly from 128.14 Mbps to 128.41 Mbps, demonstrating that the energy-saving mechanisms and radio consolidation activities did not reduce network capacity or user data rates. The stable throughput values indicate that users continued to experience the same level of 5G service quality after implementation of the Zero-Carbon architecture.

Another important KPI is the average number of connected NR users. The results show that the average user count remained unchanged at approximately 35 users before and after deployment. This confirms that network accessibility, service availability, and user retention were maintained throughout the optimization process. The ability to support the same user load while reducing power consumption highlights the efficiency of the integrated radio solution.

Overall, the NR KPI analysis confirms that the Zero-Carbon 5G-A architecture successfully delivers substantial energy savings without compromising key 5G performance indicators. The stability of throughput, latency, PRB utilization, and user connectivity demonstrates that sustainable network modernization can be achieved while maintaining high-quality

5G services. These findings validate the proposed solution as a practical approach for reducing operational energy consumption and supporting environmentally sustainable mobile network deployments.

VI. RESULT SUMMARY

The overall results of the Zero-Carbon 5G-A deployment demonstrate that substantial energy savings can be achieved without negatively affecting network performance. The proposed GigaGreen architecture successfully consolidated multiple radio layers into an integrated platform, reducing the number of radio units from seventeen to nine while maintaining full support for LTE and 5G NR services.

The energy consumption analysis revealed significant operational benefits following deployment. As summarized in Table **??**, the optimized architecture achieved an average daily energy saving of approximately 27.66 kWh per site, corresponding to a reduction of nearly 32% in power consumption. These results confirm the effectiveness of radio consolidation and AI-driven power management techniques in reducing network energy requirements.

The LTE KPI analysis, presented in Table **??**, showed that network performance remained stable after implementation. Key indicators including PRB utilization, throughput, and user activity exhibited only minor variations, demonstrating that the energy optimization process did not compromise LTE service quality. Similarly, the NR KPI comparison in Table **??** confirmed that 5G network performance was preserved, with stable throughput, latency, and resource utilization observed across the evaluation period.

Drive test validation results further verified the effectiveness of the proposed solution. As shown in Table **??**, radio coverage, signal strength, and user throughput remained consistent across LTE and NR frequency layers following deployment. The results indicate that hardware consolidation and intelligent power-saving mechanisms did not adversely affect user experience or network accessibility.

In addition, the N71 KPI impact analysis demonstrated positive network behavior following deployment. The increase in NSA users, SgNB addition attempts, and traffic growth indicates that the low-band coverage layer successfully enhanced network accessibility and service continuity. Furthermore, the uplink performance comparison highlighted the advantages of N71 in terms of average and peak uplink throughput, reinforcing its role as an effective coverage and uplink enhancement layer within a multi-band 5G network.

Overall, the results confirm that the Zero-Carbon 5G-A architecture successfully achieves the dual objectives of reducing energy consumption and maintaining network performance. The combination of integrated multi-band radio solutions, intelligent energy-saving technologies, and infrastructure reuse provides a practical and scalable framework for future sustainable mobile network deployments.

VII. DISCUSSION

The results obtained from this study demonstrate that significant energy savings can be achieved through network modernization and hardware consolidation without compromising network performance. The implementation of the Zero-Carbon 5G-A architecture successfully reduced the number of radio units from seventeen to nine while maintaining stable LTE and NR service quality. This finding is particularly important as mobile operators continue to expand network capacity and coverage while facing increasing pressure to reduce operational expenditure and environmental impact.

The energy-saving analysis showed a reduction of approximately 32% in daily site power consumption, equivalent to nearly 27.66 kWh per day per site. Such savings can generate substantial long-term operational benefits when scaled across a nationwide network consisting of thousands of sites. In addition to lowering electricity costs, reduced power consumption contributes directly to carbon emission reduction targets and supports global sustainability initiatives. These results highlight the effectiveness of integrated radio architectures as a practical approach to achieving greener mobile networks.

From a network performance perspective, both LTE and NR KPI analyses confirmed that the optimization process had minimal impact on service quality. Key indicators such as throughput, latency, PRB utilization, and user activity remained stable after deployment. The LTE network continued to support increasing user demand, while NR performance maintained consistent throughput and low latency levels. This demonstrates that energy-efficient network architectures can coexist with high-performance mobile broadband services.

Another important observation is the role of intelligent energy-saving mechanisms such as Zero-Bit Zero-Watt technology. Traditional energy-saving approaches often involve trade-offs between power reduction and network performance. However, the results of this study indicate that AI-driven optimization can dynamically adapt resource utilization according to traffic demand, allowing substantial energy savings while maintaining service availability. This capability will become increasingly important as networks evolve toward 5G-Advanced and future 6G architectures.

Overall, the findings confirm that the Zero-Carbon 5G-A architecture provides a balanced solution that simultaneously addresses energy efficiency, operational cost reduction, and network performance requirements. The combination of multi-band radio integration, intelligent power management, and infrastructure reuse establishes a strong foundation for future sustainable mobile network deployments. As network traffic continues to grow, such architectures will play a key role in enabling environmentally responsible and economically efficient telecommunications infrastructure.

VIII. CONCLUSION

This study evaluated the performance of a Zero-Carbon 5G-Advanced site architecture deployed in a live commercial network. The proposed GigaGreen solution successfully reduced site power consumption by approximately 32% while maintaining stable LTE and NR performance. KPI analysis confirmed that user throughput, PRB utilization, latency, and traffic volume remained within normal operating ranges after optimization. Drive test measurements further validated that coverage and user experience were preserved across all tested frequency bands.

The results demonstrate that integrated multi-band radio architectures combined with intelligent power-saving mechanisms can significantly improve network energy efficiency without compromising service quality. The proposed solution represents a practical pathway toward sustainable and environmentally responsible 5G-A network deployment.

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