Empirical Analysis of Power Consumption in LTE Base Stations: Temporal Patterns and Component-Level Insights

Mowadah Abdulmawlay[1], Salahedin Rehan[1,‡], Sana Ghallab[1] , Mahmud Ammar[2]

‡Advanced Technology and Communication Research Group

[1]Dept. Electrical and Electronic Engineering, Faculty of Engineering, University of Zawiya, Libya
[2]Dept. Computer Engineering, Faculty of Engineering, University of Zawiya, Libya

---

Abstract - *This paper presents a comprehensive empirical study of energy consumption within an operational urban LTE Radio Access Network (RAN). Using both site-level measurements and aggregated multi-eNB data collected over a typical workweek, the study analyses traffic trends, PRB utilization, and base station power draw across a 24-hour cycle. Results reveal a clear temporal mismatch between network load and energy use, with minimal reduction in power consumption despite significant drops in user activity and PRB utilization during off-peak hours. A linear relationship between PRB utilization and power consumption is established, exposing a baseline energy overhead largely independent of traffic load. Additionally, component-level measurements from a live site highlight that Remote Radio Units (RRUs) and baseband modules account for most of the energy use, while also uncovering key operational dependencies and startup sequences between network elements. These insights underscore the importance of real-world profiling to support the development of energy-aware RAN designs and optimization strategies grounded in operational realities.*

Key Words: RAN Energy Profiling, Base Station Power, PRB Utilization, Urban Cellular Networks, Green Communications

1. INTRODUCTION

The exponential growth in mobile data demand, driven by ubiquitous smartphones and bandwidth-intensive applications, has led to a dramatic expansion in cellular infrastructure worldwide. Among the components of a mobile network, the Radio Access Network (RAN) is by far the most energy-intensive, with base stations (BSs) alone responsible for up to 80% of the network's total energy consumption [1]. This presents a major sustainability challenge, particularly in urban LTE deployments where dense site layouts are common, and energy usage remains largely static despite fluctuating traffic loads [2]. In response, major industry alliances have outlined strategic roadmaps to reduce energy consumption in mobile networks, with particular focus on RAN efficiency, hardware modularity, and real-time energy management frameworks [3]. In principle, the energy consumption of a base station should vary with user activity and service demand. In practice, however, BSs typically operate at nearly constant power levels throughout the day, regardless of traffic volume [4]. This inefficiency has spurred considerable interest in developing energy-saving mechanisms such as cell switch-off, component-level sleep modes, and AI-driven traffic prediction to reduce unnecessary energy usage during low-load periods [5–7]. Recent advances in AI-powered RAN optimization have demonstrated promising results in dynamic energy management, allowing base stations to adapt power usage in near real-time based on traffic patterns and environmental conditions [8]. In parallel, standardization efforts—such as those outlined by 3GPP in TR 36.927 Release 16—have proposed enhancements for energy efficiency in E-UTRAN, including sleep-mode operation, component-level scaling, and intra-/inter-eNB coordination techniques [9].

Much of the existing literature has relied heavily on simulations or theoretical modelling to evaluate such energy-saving strategies. While valuable, these approaches often lack real-world validation, particularly in live LTE deployments where network configurations, user distributions, and operational policies may differ significantly from theoretical assumptions. Recent work in the 5G and beyond-5G domain has explored numerous energy efficiency frameworks at both the network and component level [10], yet empirical analysis in 4G LTE environments remains sparse. This gap underscores the importance of empirical studies that measure actual energy consumption and its correlation with network load.

This paper contributes to this space by presenting a detailed energy profiling study of an operational LTE RAN in a North African capital city. The analysis is based on two complementary data sources: (1) live power readings collected on-site from a monitored macro eNB, which allow for component-level breakdown of energy usage, and (2) aggregated performance metrics obtained from multiple base stations in the same urban area, capturing trends in user count, PRB utilization, throughput, and instantaneous power consumption over a 24-hour cycle.

Unlike purely simulation-based work, this study grounds its analysis in real-world measurements. Key insights include the temporal misalignment between traffic demand and power draw, the disproportionate energy usage by specific hardware components, notably RRUs and baseband units, and a quantifiable linear correlation between PRB utilization and total power consumption. In addition, the analysis uncovers critical operational dependencies and startup sequences between network elements, such as the activation order of MMUs, BBUs, and RRUs, which are essential considerations when developing practical, energy-aware control strategies. These findings are essential for designing deployment-aware optimization mechanisms that align with the operational realities of existing 4G networks.

The remainder of this paper is organized as follows: Section 2 describes the data sources and methodology used in our analysis. Section 3 presents the energy profiling results, including component-level and temporal energy trends and discusses key findings and their implications for green RAN operations. Finally, Section 4 concludes the paper and outlines future research directions.

2. METHODOLOGY

This study is based on a two-fold empirical dataset gathered from a live LTE network operating in a North African capital city. The aim was to analyse real-world energy consumption behaviours across urban macro base stations (eNBs), including both temporal usage patterns and internal component-level power distribution.

2.1. Network Scope

The analysis covers a cluster of 13 macro-LTE eNBs deployed in a densely populated urban district. These eNBs are part of a commercial-grade LTE network and serve a wide range of users under varying daily load conditions. Each site employs typical configurations found in 4G deployments, including multi-sector antennas and standardized radio/baseband equipment.

2.2. Data Sources and Acquisition

Two distinct data sources were used. The first is an aggregated operational data provided by the network operator; this dataset includes:

- Hourly user equipment (UE) counts per cell
- PRB (Physical Resource Block) utilization
- Throughput metrics
- Instantaneous power consumption for each eNB.

These values span a full 24-hour operational period across a typical week, enabling temporal analysis of traffic–energy correlation.

The second dataset comprises of site-level power measurements. Live measurements were collected during a field visit to one selected eNB. Using internal monitoring tools and power sensors integrated within the site infrastructure, we recorded the component-wise power consumption, including Remote Radio Units (RRUs), Baseband Units (BB), and other supportive modules (e.g., MMUs, fans, power converters). These readings formed the basis for component-level energy profiling.

In line with institutional and operator data-sharing agreements, no proprietary identifiers, site IDs, or internal naming schemes can be disclosed in this paper. All insights are reported at an abstracted level and reflect aggregate behaviour patterns rather than device-specific records.

3. Results and Observations

The collected data was processed to extract usage trends, visualize correlations, and estimate component-wise energy contributions. The following subsections present the findings in terms of temporal patterns, hardware-level consumption, and traffic–energy relationships observed across the urban LTE RAN.

3.1. User Load and PRB Utilization Patterns

Figure 1 shows the number of user equipment (UEs) in the RRC_CONNECTED mode over a period of a week across the 24-hour cycle. As expected, network activity follows a daily trend, with minimal load between 4:00 AM and 11:00 AM and peak usage occurring in the evening hours. Based on this behaviour, the network's operational timeline can be divided into three distinct regions: (i) a very low traffic period from 4:00 AM to 11:00 AM, (ii) a moderate-load period from 11:00 AM to 8:00 PM and again briefly from 2:00 AM to 4:00 AM, and (iii) a high-demand period extending from 8:00 PM to 2:00 AM. These regions reflect fundamentally different service demands and constraints and should not be treated uniformly in energy management schemes. The early morning window (4:00 AM to 11:00 AM), characterized by network underutilization and abundant idle resources, presents the most viable target for implementing energy-efficient mechanisms. In such conditions, a trade-off favouring reduced power consumption over peak spectral efficiency becomes both feasible and beneficial for LTE deployments.

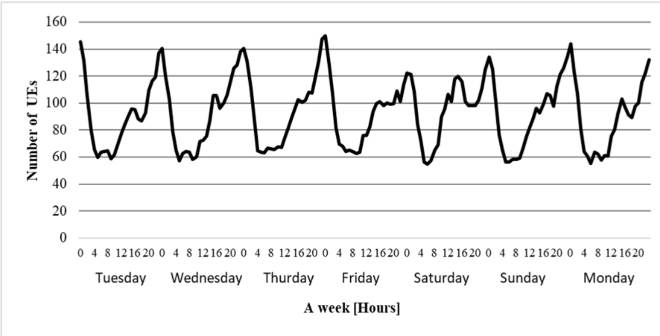

Fig -1: Number of UE in 24 hours

Figure 2 presents the average PRB utilization across thirteen eNBs over a five-day weekday period (Sunday to Thursday). Weekend data was excluded due to differing usage dynamics. PRB utilization serves as a reliable proxy for network load, reflecting how spectrum resources are allocated over time. The trend highlights very low PRB utilization between 4:00 AM and 11:00 AM, corresponding to the low-traffic region identified earlier. During these hours, average utilization falls to approximately 10%, while in peak hours, particularly between 8:00 PM and 2:00 AM, it surges to above 80%. This nearly eightfold difference indicates substantial underutilization of network resources during off-peak hours.

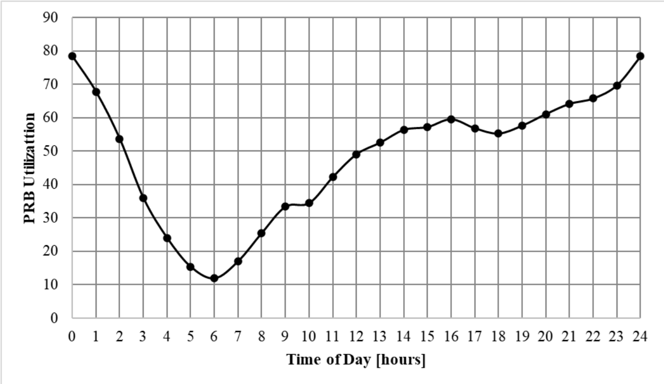

Fig -2: PRB Utilization Throughput in 24 hours

Such a disparity underscores the potential for energy-saving strategies that align power usage more closely with actual traffic demand. The early morning window, in particular, presents a compelling opportunity for adaptive energy management in LTE networks.

Figure 3 illustrates the average instantaneous power consumption over working days (Sunday to Thursday). Although network traffic shows significant fluctuation throughout the day, power consumption remains relatively stable, with only about a 25% reduction from peak to off-peak hours. This is in stark contrast to the 80% drop in PRB utilization observed over the same period.

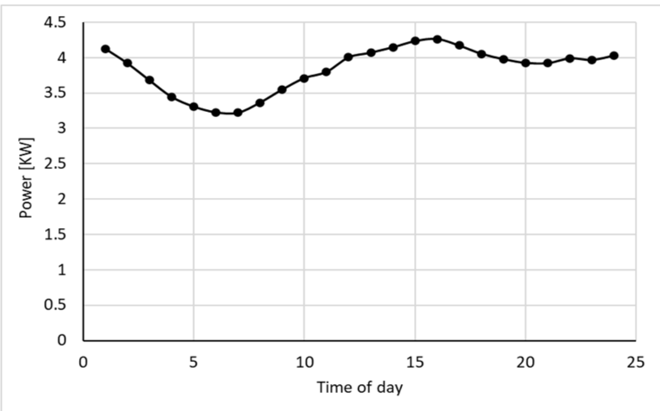

Fig - 3: The instantaneous power consumption

This mismatch clearly highlights the inefficiency in energy scaling within the LTE RAN, where hardware components remain fully powered even when traffic is minimal. The early morning window, combining low PRB utilization with nearly full power draw, represents a zone of excessive energy waste and underutilized capacity. These findings emphasize the importance of understanding not only how traffic varies, but also how energy is consumed at the base station level in response to load.

The observed relationship between PRB utilization and power supports the idea that energy efficiency enhancements are both necessary and feasible, particularly when guided by accurate, real-world data.

3.2. Power Consumption vs. Network Load

A correlation analysis was performed between PRB utilization and instantaneous power consumption across the 13 eNBs averaged over five weekdays. As shown in Figure 4, a linear relationship was observed, approximated by the model, where *y* represents power consumption in kilowatts and *x* denotes PRB utilization as a percentage.

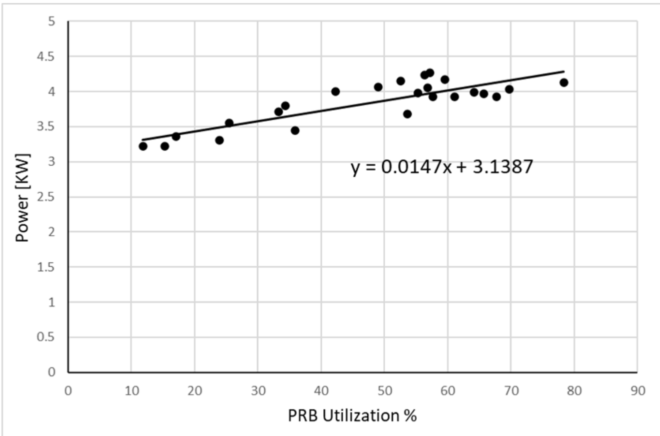

Fig - 4: Instantaneous consumption vs PRB utilization

This model indicates that each 1% increase in PRB utilization contributes only 0.0147 kW of additional power draw—while the base station still consumes approximately 3.14 kW even when it is idle, with no user data to transmit. This highlights a structural energy inefficiency, where the majority of power expenditure is tied to baseline operation rather than active traffic handling. The simplicity and consistency of this correlation make it a useful empirical tool for estimating site-level energy needs under varying traffic loads, and it reinforces the potential for load-aware energy management in LTE networks.

3.3. Component-Level Energy Breakdown

The study included a detailed assessment of a live macro eNB site operating in a densely populated urban area. The site features standard components found in commercial LTE deployments: a power supply unit (comprising rectifiers, a controller, and a DC-UD unit), a Memory Management Unit (MMU), two baseband units (BBUs) supporting 2G–3G and 4G RRUs, Remote Radio Units (RRUs) mounted on the tower, and an integrated cooling system. The site is designed to operate at full load using both direct power input and backup battery capacity. In normal conditions, the system draws a constant 48 A. The battery bank, consisting of sealed non-spillable batteries rated at 63–100 Ah, allows for off-grid operation of up to 8 hours, with expansion underway to extend autonomy up to 24 hours.

Figure 5 presents the power consumption distribution among these components. RRUs and BBUs constitute the largest share of energy usage, while the MMU, power conversion system, and cooling unit consume relatively less. The total site power loss due to heat and miscellaneous inefficiencies is reported to be around 2% of the input, with 98% converted into usable DC output.

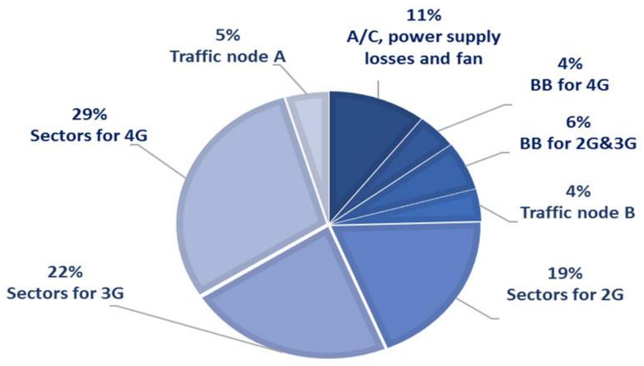

Fig - 5: Power consumption distribution on visited site

In addition to quantifying energy distribution, operational startup dependencies between components were observed. The MMU is the first component to activate, establishing communication with the core network controller to authenticate and fetch permissions, licenses, and security credentials. It then initiates the boot-up sequence of the BBUs, which in turn activate their respective RRUs. The full startup process, depending on RNC response times and backhaul latency, takes approximately 10 to 15 minutes, with each stage requiring 3 to 5 minutes.

While many energy-saving strategies are typically evaluated through simulations, real-world measurements reveal subtle inefficiencies, static configurations, and component-level dynamics that simulations often overlook. This reinforces recent observations in the literature that while RAN energy efficiency is emphasized in standards and academic models, its adoption in operational environments remains inconsistent and highly context dependent [11]. A deep understanding of both energy distribution and startup sequencing is essential—not only for accurate profiling, but also for informing future optimization strategies such as intelligent scheduling, adaptive resource management, or selective component scaling. This study contributes to closing that gap and provides concrete guidance for data-driven, energy-aware RAN design.

4. CONCLUSIONS

This study presented a detailed empirical profiling of energy consumption in an operational urban LTE RAN, using both aggregated network performance data and direct site-level measurements. The analysis revealed significant temporal mismatches between user demand and energy use, with base stations consuming nearly constant power despite major fluctuations in PRB utilization and active users.

By segmenting the network load profile into distinct operational regions, we identified a clear opportunity for energy optimization during low-traffic hours, particularly between 4:00 AM and 11:00 AM. The observed linear correlation between PRB utilization and power consumption highlights how minor traffic variations contribute minimally to energy savings under current configurations. Moreover, component-level measurements confirmed that RRUs and baseband units dominate energy use, while also revealing the startup dependencies and timing requirements between functional blocks such as MMUs and RRUs.

REFERENCES

[1] M. A. Imran, E. Yaqub, and R. Tafazolli, "Energy Efficiency in 5G Networks: A Holistic Overview," IEEE Access, vol. 9, pp. 123105–123124, 2021.

[2] ITU-T, "ICTs for e-Environment," International Telecommunication Union, 2021. [Online]. Available: https://www.itu.int

[3] NGMN Alliance, A Roadmap to Energy Efficient Mobile Networks, Next Generation Mobile Networks (NGMN) Alliance, July 2024. [Online]. Available: https://www.ngmn.org/wp-content/uploads/GFN_Energy_Efficiency_Roadmap_V1.0.pdf

[4] C. Turyagyenda, D. K. Kwayu, and C. A. Shonubi, "Energy Saving in 5G Networks Through Adaptive Sleep Modes: A Review," IEEE Access, vol. 10, pp. 8415–8430, 2022.

[5] M. El-Khamy, H. Yoo, and J. Lee, "AI-Driven Network Optimization for Green RAN Operations," IEEE Communications Magazine, vol. 60, no. 11, pp. 73–79, Nov. 2022.

[6] A. Zappone, M. Di Renzo, and M. Debbah, "Understanding, Modeling, and Analyzing Wireless Networks: From Shannon to Machine Learning and Beyond," IEEE Access, vol. 7, pp. 167229–167245, 2019.

[7] T.K. Chien, L. C. Wang, and S. C. Lin, "Energy Efficiency Analysis of LTE Small Cell Networks," IEEE Transactions on Vehicular Technology, vol. 69, no. 6, pp. 6480–6493, June 2020.

[8] P. Sharma, M. Olsson, and H. Kang, "AI-powered RAN: An Energy Efficiency Breakthrough," Ericsson Blog, Jan. 2023. [Online]. Available: https://www.ericsson.com/en/blog/2023/1/ai-powered-ran-energy-efficiency

[9] 3GPP, TR 36.927 V16.0.0: Energy Saving Enhancements for E-UTRAN – Stage 2 (Release 16), 3rd Generation Partnership Project, July 2020.

[10] A. Ichimescu, S. Dobrescu, and V. Constantin, "Energy Efficiency for 5G and Beyond 5G: Potential, Limitations, and Future Directions," Sensors, vol. 24, no. 22, p. 7402, 2024.

[11] L. Kundu, X. Lin, and R. Gadiyar, "Towards Energy Efficient RAN: From Industry Standards to Trending Practice," arXiv preprint, arXiv:2402.11993, 2024.