A 5G Americas Briefing Paper
Dec. 2023

# ENERGY EFFICIENCY AND SUSTAINABILITY IN MOBILE COMMUNICATIONS NETWORKS

## Purpose

Sustainability is one of the most urgent and pressing challenges of our time, and affects the telecommunication sector as much as any other industry. Mobile network operators (MNOs) and vendors have set aggressive sustainability targets for the next decades towards carbon footprint reduction, and ultimately Net Zero emissions. The carbon footprint of operating the mobile network is primarily determined by the overall energy consumption from running the network, as well as the carbon emission intensity of the energy sources used. This white paper analyses the key strategies and technologies to enable energy-efficient operation of mobile networks, the potential inclusion of alternative or renewable energy solutions as part of mobile infrastructure, and the growing efficiency impact of connectivity solutions generally in all operations and services. The strategies and technologies discussed in this white paper are foundational to understanding the mobile industry's potential for enabling positive sustainability impact for planet and society. With the focus on energy efficiencies to run 5G networks, this white paper aims to place the sustainability objectives in the larger context while setting the stage for the specific techniques available today and potential new capabilities to be explored.

## Background

The triple bottom line drivers for enabling the de-carbonization of mobile industry are given as follows:

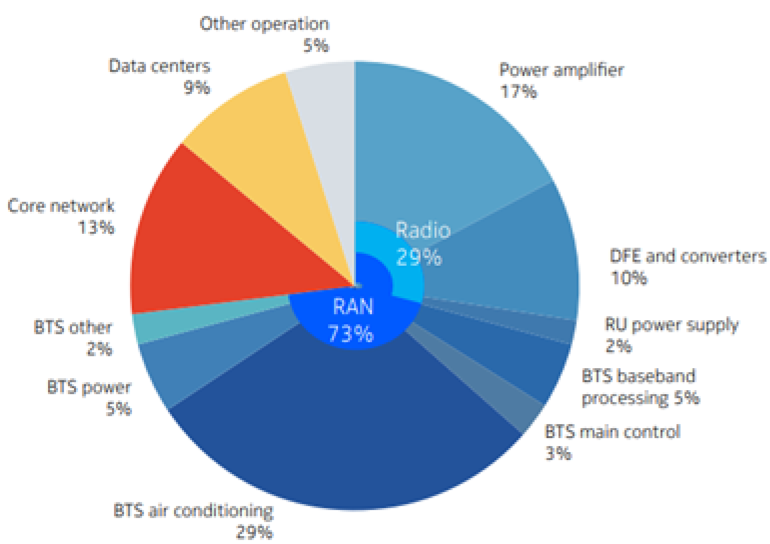
- **Environmental:** While demand for mobile networks continues to grow, without action, network energy use and related carbon emissions will too. Reaching Net Zero is a challenge, that will require the ICT industry to "do more with less" and decouple data growth from energy consumption.
- **Social:** Universal and affordable access to the internet for all continues to be an unrealized objective. In the United States, there is disparity between individual states in terms of school connectivity, increasing the speed and broadband connectivity to match the highest levels available in the US can result in a 5.5% increase in GDP by 2025[1]. Eliminating the digital divide will require investment in the reach and capacity of mobile networks which will come with additional GHG emissions that must be offset to achieve net-zero goals[2].
- **Economic:** The estimated annual energy cost for running mobile networks is about $25B[3], for mobile network operators' energy consumption constitutes between 20 – 40% of network OPEX[4]. With the recent energy crisis and increasing network energy use these numbers are expected to be higher. This makes securing energy consumption of mobile networks an economic and environmental imperative.

Approximately 95%[5] of the product life cycle emissions associated with mobile communications networks occur during their operational use, thus are associated with the use of energy. Therefore, the main strategy for de-carbonizing the operational emissions of the mobile industry requires complementary and urgent implementation of energy efficiency and energy-saving measures as well as switching to renewable or low carbon source of energy to power mobile networks. Accordingly, this paper analyses strategies to enable energy-efficient operation of mobile networks, implementing alternative or renewable energy solutions and efficient operations of services using connectivity solutions.

## Current Status

Currently, within the landscape of modern mobile networks, a substantial majority of energy is consumed within the radio access network (RAN) domain. As delineated in Figure 1, an astonishing 73% of the total energy consumption is attributed to the radio access network (RAN). Comparatively, the core network and proprietary data centers account for 13% and 9% of the energy usage respectively, with other operational components representing the remaining 5%. The share of energy consumed by the RAN can vary depending on the operator configuration and equipment, and be between 70-85% of the total energy consumption in the network. Within the RAN, the radio components such as the power amplifier are the key contributors to the overall RAN power consumption. Notably, recent innovations such as RAN site components that can be used outdoors, have significantly reduced the need for cooling. In general, the less active air cooling is used and the more radio units are placed outdoors, the closer the share of energy consumption for cooling drops towards 10% rather than 29% as shown in Figure 1. Given that the RAN domain constitutes the predominant consumer of energy within the mobile network, the RAN is unequivocally the primary focus for scrutiny and intervention in energy-saving endeavors.

**Figure 1: Network Power Consumption Split by Domain. Source: Nokia Bell Labs[6] (based on NGMN data[7]).**




## Key Information

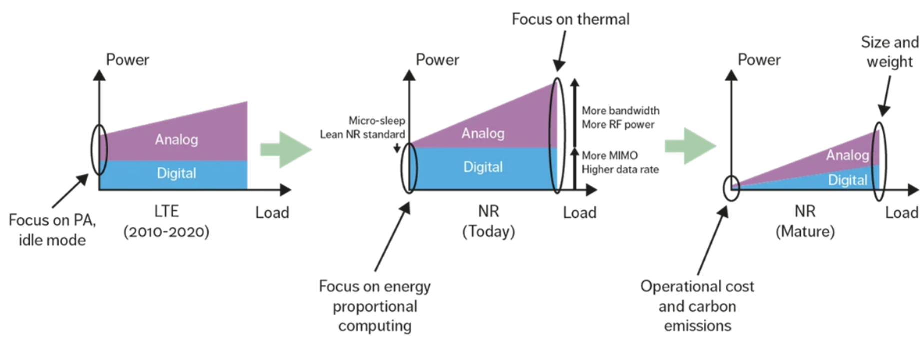
Mobile networks must minimize energy consumption and optimize energy utilization and energy sources while running the network to reduce their environmental impact and greenhouse gas emissions. Therefore, we analyze the key strategies and technologies to reduce direct greenhouse gas emissions associated with the use of mobile communications within ICT and the de-carbonization potential of therein. We focus specifically on topics related to energy efficiency in the network using RAN techniques in the time, spatial, frequency and power domains as well as in the core network, and in addition we analyze system architecture enablers and deployment strategies.

### Energy-Efficient RAN

The radio access network (RAN) domain is the primary focus for energy-saving efforts, as it accounts for 73% of total energy consumption in mobile networks (see Figure 1). Key techniques to enhance RAN's energy efficiency include adaptations of radio network parameters in time, frequency, spatial, and power domains in response to traffic variations. These adaptive capabilities play a pivotal role in optimizing power consumption while maintaining network performance. In general, it is expected that while attaining improved energy efficiency and energy saving, the network should not impact negatively individual user QoE and should apply the adaptations carefully depending on the number of active subscribers. However, in certain cases a balance between end-user QoE and energy saving may be considered.

Figure 2 illustrates the evolution of the power consumption of the radio unit in the base station[8], which has a large weight to the power consumed by the entire base station (see Figure 1). In the first stage, improving network energy efficiency primarily involved time-domain techniques such as reducing idle mode consumption since load dependence was not a significant factor. Figure 2 further shows how the power consumption becomes increasingly dependent on the network load when cellular networks transition from one generation to another. Thus, in the next stages, adaptation in frequency (bandwidth), power and antenna domains become more relevant.

**Figure 2: The power consumption journey of the radio unit in the base station**




In the time-domain, micro-sleep techniques are very effective means to conserve energy by deactivating and reactivating power amplifiers during idle periods. The lean carrier design of 5G New Radio (NR) enabled improved sleep opportunities than LTE as it removed the always-on cell-specific reference signaling of LTE.

In the frequency domain, carrier aggregation can expand coverage using lower frequency bands while efficiently boosting capacity by moving user-plane data to higher bands. Furthermore, innovations such as spectrum sharing enable single service providers to deploy new frequency bands on existing infrastructure without sacrificing performance or environmental sustainability goals.

Current advancements like massive MIMO systems provide exceptional spectral efficiency through use of active spatial elements based on factors like traffic load and user radio conditions. Massive MIMO systems used in downlink transmissions possess numerous spatial elements that can be associated to one or more power amplifiers. Accordingly, spatial domain adaptations entail evolving 5G and 5G-Advanced base stations with adaptive capabilities that allow them to activate or deactivate specific spatial elements such as antenna ports and antenna elements depending on traffic load conditions to optimize power consumption without negatively impacting user experience.

Power amplifiers (PAs), which consume a significant portion of a base station's power, can be optimized by employing digital pre-distortion (DPD) techniques. DPD techniques have been widely implemented by pre-distorting the transmitted signal so that it remains non-distorted after passing through PA non-linear distortion. These techniques improve PA efficiency by operating closer to its saturation point while maintaining good linearity, and thus can mitigate non-linear impairments introduced by PAs. However, with massive MIMO systems calculating DPD becomes more challenging. To address this issue, over-the-air training can be used where receivers estimate and feedback composite non-linearity information instead of having separate DPD correction per transmitter antenna element chain which is costly both regarding die area size and power consumption. However, the overall complexity of such solutions remains quite high.

In conclusion, adopting adaptive capabilities based on load and radio conditions across various radio domains are essential for modern base stations and RAN sites geared towards enhanced network performance while reducing power consumption, and in turn environmental impact. Furthermore, the 3GPP enablers are continuously developed in 5G-Advanced and expected in the 6G design to enable radio adaptations to be more dynamic and at a more granular level than in today's networks so to exploit further energy saving potentials[9,10,11].

### AI/ML Enablers for Sustainability

AI/ML frameworks play a crucial role in enhancing energy efficiency and sustainability in the telecommunications industry. These technologies optimize energy-saving solutions at various stages of network planning and operations, enabling communication service providers (CSPs) to design and deploy network resources with precision without negatively impacting individual users' QoE (Quality of Experience)[12] [13].

Key applications of AI/ML tools for network energy reduction include precise network planning, dynamic allocation of resources within the RAN, control loops optimization for shutdown/restart services, virtual drive tests based on AI predictions using real data, proactive risk management through deeper understanding of networks and users' behavior patterns. For example, AI/ML-driven predictions and energy-saving functionalities that make real-time decisions can effectively manage resources and reduce energy consumption during periods of low network usage.

Furthermore, AI-powered benchmarking measures provide accurate insights into the performance metrics while reducing costs associated with manual benchmarking practices. Additionally, 3GPP enablers are introduced to define required signaling/data analytics used by AI/ML algorithms.

Innovative techniques leveraging AI/ML capabilities are being explored extensively in the industry. For example: RAN Intelligent Controller (RIC) applications can automatically adjust remote radio unit outputs based on traffic patterns; virtualization platforms enabled with analytics/prediction models can shut down instances during periods of low usage; specialized software companies can optimize Service Management & Orchestration layer in ORAN solutions; smart building controllers use connectivity intelligently for conserving energy/improving health/safety/reducing staffing costs etc.

The role of AI/ML as a key enabler in sustainability extends beyond just improving efficiency but also offers benefits related to overall environmental impact reduction such as carbon emission reductions due to optimized streaming video/XR applications etc., IoT-based monitoring/tracking systems enabling other industries' efficiencies improvements through partnerships between connectivity providers/corporate enterprises & more efficient use/deployment renewable energies/site solutions etc., which all contribute towards achieving Net Zero goals set by ICT industry groups worldwide.

## Energy-Efficient Deployment and Architecture Strategies

Deployment strategies for wireless networks also play a crucial role in achieving energy savings by considering aspects like cost-effectiveness, environmental impact, regulatory compliance, societal acceptance while choosing between different approaches such as small cell densification or indoor solutions.

Small cell densification is an architectural trend that focuses on energy-efficient network designs through the deployment of small cells or multi-TRP base stations with remote radio heads. However, densification may not always be economically sustainable due to increased operational expenses and carbon footprint.

Indoor 5G deployments using In-building Wireless Systems offer significant advantages over traditional Distributed Antenna System solutions consuming less power while providing better coverage/service quality indoors where majority cellular traffic originates or terminates.

RAN sharing is another approach to increase sustainability by allowing multiple operators to share RRUs, minimizing redundant radio equipment. Resource Allocation models based on network slicing enable efficient sharing of RAN equipment between multiple operators while ensuring performance requirements are met. AI-Assisted Multi-Operator RAN Sharing can significantly improve network energy efficiency without compromising throughput in scenarios involving multiple MNOs. RAN Sharing and Shared Infrastructure can effectively reduce the energy consumption footprint of mobile networks by allowing operators to share resources. This enables dynamic pooling of RAN resources among operators for energy saving beyond traditional static network sharing agreements. Case studies show that shared radio configurations can save up to 42% in energy consumption.

System Architecture Solutions for Energy Efficiency should primarily focus to facilitate efficient energy use and savings in the RAN as it consumes the largest amount of energy in the entire mobile network, and secondarily in the core network infrastructure as well. Virtualization, Open RAN, and network slicing are some enablers that contribute to increased sustainability and power efficiency.

Virtualization and Open RAN technologies allow more efficient use of resources by enabling elastic scaling (using only required resources) and resource pooling (efficiently sharing resources across multiple operators). NFV deployments leverage container-based frameworks like Docker and Kubernetes for packaging orchestration which provides opportunities for reducing energy consumption through optimized workload instantiation. By adopting network virtualization, operators can replace dedicated physical devices with generic hardware platforms running equivalent functions implemented in software. This shift towards software-based networks has evolved into cloud-native architectures based on microservices. Additionally, orchestration frameworks enabled with analytics allow shutting down instances of Software-based Network Functions during periods of low usage to reduce power consumption.

Governments, national regulators, industry bodies support infrastructure sharing as it leads to direct savings in terms of reduced duplication costs as well as lower overall power consumption resulting from shared facilities/resources usage leading towards a greener environment.

The Open RAN initiative aims at increasing competition between vendors for more advanced innovation in RAN components leading to increased power amplifier efficiency. AI/ML optimization of SMO layer could reduce power consumption by up to 12%.

Artificial Intelligence (AI) and Machine Learning (ML) applications within the RIC can automatically adjust RRU outputs based on traffic patterns and usage demand for optimized efficiency.

### Energy-Efficient Applications and Services

Energy consumption is a significant concern when it comes to video streaming – both on the user-side and network-side. To address this issue, traffic shaping techniques are employed by mobile networks to identify and rate limit video streams based on packet heuristics. This approach not only saves capacity over air interfaces but also improves user experience by prolonging battery life.

HTTP Adaptive Streaming (HAS) is the primary method used for delivering streaming video. It involves user devices requesting “chunks” of video content via HTTP to populate a playout buffer on the device. The adaptive nature of HAS allows for adjustments in response to network congestion or varying display sizes.

Greening of Streaming is an initiative focused on enhancing energy efficiency across the technical supply chain underpinning streaming services. One notable effort within this initiative is defining the LESS Accord (Low Energy Sustainable Streaming), which outlines best practices for employing compression technologies while maintaining good quality viewer experiences.

Operators benefit from shaping video as it creates more capacity in their networks while improving user quality-of-experience through extended battery life. Additionally, media delivery optimization can help reduce energy usage throughout mobile networks.

With increasing reliance on video streaming services worldwide comes greater responsibility towards ensuring sustainable practices are implemented throughout every aspect involved in delivering these services - from network infrastructure management down to individual end-user experiences - ultimately contributing towards a greener future for all stakeholders involved in this rapidly evolving industry landscape

AT&T Video Optimizer, for example, is a tool that helps app developers enhance app performance while promoting efficient use of mobile networks globally – leading to improved environmental benefits resulting from optimized app code implementation.

Media delivery optimization over mobile networks can also contribute towards reduced energy usage from content providers all the way down to mobile devices. Traffic shaping techniques save both capacity over air interface networks while prolonging battery life for user devices without impacting quality-of-experience.

## Alternative Energy sources

As the world moves towards sustainable energy solutions, alternate energy sources are becoming increasingly important. Solar and wind power are two of the most prominent renewable energy sources that can significantly reduce carbon emissions.

Solar power can be utilized in various ways, such as designing and installing enough solar capacity for excess electricity to be sent back to the grid during peak generation hours. This model is sometimes referred to as “grid-as-a-battery.” Alternatively, a battery energy storage system (BESS) can be provisioned along with solar panels if the grid does not provide energy credits or support bi-directional electricity meter applications. Deploying solar panels at cell sites with excess real estate could also significantly reduce carbon emissions. In combination with battery storage systems or grid-as-a-battery models where excess solar-generated electricity is sent back into the grid during peak generation hours for credit against non-daylight hour usage – renewable energies can lead not only towards net-zero emissions but also operational expenditure reductions.

Wind energy is another path towards reducing carbon emissions. Wind turbines generate renewable energy by harnessing wind power. There are two main types of wind turbines: Horizontal-axis wind turbines (HAWT) and Vertical-axis wind turbines (VAWT). HAWTs are more efficient than VAWTs but require more space for optimal performance, making them suitable for open rural spaces. VAWTs operate better in slower or turbulent winds and can be placed closer together, making them ideal for urban or suburban environments.

In addition to these renewable sources, smart building technology plays a major role in delivering sustainable outcomes by leveraging connectivity strategies like Ethernet/UPOE+, 5G, Wi-Fi networks which enable monitoring and optimization across entire physical asset bases using near-real-time IoT data analytics tools like Efficiency-as-a-Service (EaaS), Energy & Building Management Solution (EBMS).

## Connectivity as a Sustainability Enabler

A significant percentage of Fortune Global 200 companies have established targets for the partial or total elimination of GHG emissions, and many of these businesses have set dates for reaching carbon neutrality. Many 5G Americas companies have set targets for reaching these goals.

Connectivity-based solutions enable businesses to monitor, track, and optimize operations across industries manufacturing agriculture commercial sectors and achieve their sustainability goals.

Smart building technology is also an essential aspect of achieving sustainable outcomes. Connectivity strategies that include wired and wireless technologies, such as Ethernet/UPOE+, 5G, and Wi-Fi, enable smart buildings to monitor and optimize operations for energy conservation, health and safety improvements, and staffing cost reduction.

There are new platforms from communication vendors and providers that help companies overcome obstacles to large-scale energy efficiency deployments for building management solutions. Most of these are data-driven solutions to realize energy and operations savings across large, distributed portfolio of buildings.

Building Management Solutions help businesses reduce energy use across entire physical asset base, driving operational agility using near-real-time IoT Data, employing Big Data Analytics for actionable insights and ensuring predictable building and facility maintenance tasks while extending HVAC systems and control lifecycle.

In conclusion, connectivity plays a crucial role as a sustainability enabler for all industries worldwide.

## Recommendations

This paper introduced existing technical capabilities, deployment strategies and other operational techniques that can be used by mobile network operators to increase energy efficiencies, reduce energy consumption to become sustainable enterprises. Operators and vendors are encouraged to implement and adopt these capabilities where fit, while continuing to invest in research towards next generation network technologies that are optimized for energy efficiency. Furthermore, this calls for applying new optimization techniques leveraging standards from 3GPP and other organizations as well as innovations from the broader ICT sector.

## Conclusion

Mobile network operators and vendors have set aggressive sustainability targets aimed at reducing their carbon footprint for the next decade along with other industries. While there are multiple techniques employed, including sourcing renewable energy for network operations, a key sustainability strategy is to reduce the overall energy consumption. This is becoming critical for 5G deployments as the network traffic is expected to increase significantly with broader adoption and deployments.

This calls for applying new optimization techniques leveraging standards from 3GPP and other organizations, innovations from the broader ICT sector such as 5G-Advanced dynamic energy saving techniques, cloud-native frameworks, virtualization and open architectures as well as more diverse deployment strategies including open RAN, small cells and shared infrastructure.

The increased demands on the 5G networks will continue with future mobile generations and energy efficiency is a key requirement and design criterion playing a significant role in shaping the specifications for 6G. It is also critical to look at efficiencies beyond the network and into the larger ecosystem such as the application layer with optimized streaming for video and other emerging applications such as XR.

Connectivity plays a key role in enabling other industries to become more energy-efficient and using 5G IoT solutions in manufacturing, agriculture and other verticals empowers players in these industries to track, manage and optimize their operations towards a more sustainable future.

## Acknowledgments

5G Americas' Mission Statement: 5G Americas facilitates and advocates for the advancement of 5G and beyond throughout the Americas.

5G Americas' Board of Governors members include Airspan Networks, Antel, AT&T, Ciena, Cisco, Crown Castle, Ericsson, Liberty Latin America, Mavenir, Nokia, Qualcomm Incorporated, Samsung, Rogers Communications, T-Mobile USA, Inc., Telefónica, VMware and WOM.

5G Americas would like to recognize the significant project leadership and important contributions of group leaders Dan Druta, Lead member of Technical Staff, AT&T, Humberto LaRoche, Principal Engineer, Cisco and Daniela Laselva, Distinguished Member of Technical Staff, Nokia along with many representatives from member companies on 5G Americas' Board of Governors who participated in the development of this white paper.




## Endnotes


1 https://connectinglearners.economist.com/connecting-learners/

2 https://www.nokia.com/blog/the-big-picture-or-the-bottom-line

3 https://www.ericsson.com/en/news/2022/10/ericsson-publishes-breaking-the-energy-curve-report-2022

4 https://www.gsma.com/futurenetworks/wiki/energy-efficiency-2/

5 https://www.nokia.com/networks/zero-emission-mobile-networks/#sources-of-co2

6 https://www.bell-labs.com/institute/white-papers/energy-efficiency-in-next-generation-mobile-networks/

7 https://www.ngmn.org/ publications/green-future-networks-network-energy-efficiency.html

8 Improving energy performance in 5G networks and beyond - Ericsson

9 https://www.3gpp.org/ftp/Specs/archive/38_series/38.864/38864-i10.zip

10 Nokia: Reducing energy use with 5G-Advanced

11 M. Oikonomakou, A. Khlass, D. Laselva, M. Lauridsen, M. Deghel, and G. Bhatti, "A power consumption model and energy saving techniques for 5G-Advanced base stations," IEEE ICC 2023, Rome, Italy, 2023, pp. 605-610, doi: 10.1109/ICCWorkshops57953.2023.10283643

12 https://www.ericsson.com/en/blog/2023/6/intelligent-sustainability-ai-energy-consumption

13 https://www.nokia.com/networks/bss-oss/ava/energy-efficiency/