A 5G AMERICAS WHITE PAPER

# ENERGY EFFICIENCY AND SUSTAINABILITY IN MOBILE COMMUNICATIONS NETWORKS

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# Contents

# Executive Summary

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.

Chapter 2 delves into detailed RAN techniques to reduce energy consumption through radio adaptations in the time, frequency, spatial and power domains, and explores the role AI/ML plays in leveraging these techniques as well as other operational efficiencies.

Chapters 3 and 4 examine the system architecture enablers such as network slicing, virtualization, and Open RAN, bringing these key network architecture elements in the context of sustainability and power efficiency. They also explore network deployment and architectural options with industry case studies on small cell rollouts, indoor coverage and other alternatives for efficient, flexible and scalable networks. The chapters also investigate RAN sharing and shared infrastructure as ways to increase sustainability and energy efficiency in mobile networks while presenting opportunities and challenges that the industry needs to overcome with these approaches.

Since energy consumption correlates directly with the traffic generated by users, Chapter 5 digs into the application layer optimizations that can potentially reduce traffic volumes and subsequently reduce energy usage, especially on the RAN side.

In Chapter 6, the potential and challenges of site solutions enabling renewable energy solutions are discussed.

Finally, no sustainability story is complete without articulating the benefits that connectivity brings to the larger ecosystem. Chapter 7 discusses how mobile communications, with the help of IoT solutions, can enable other industries to reach their sustainability goals.

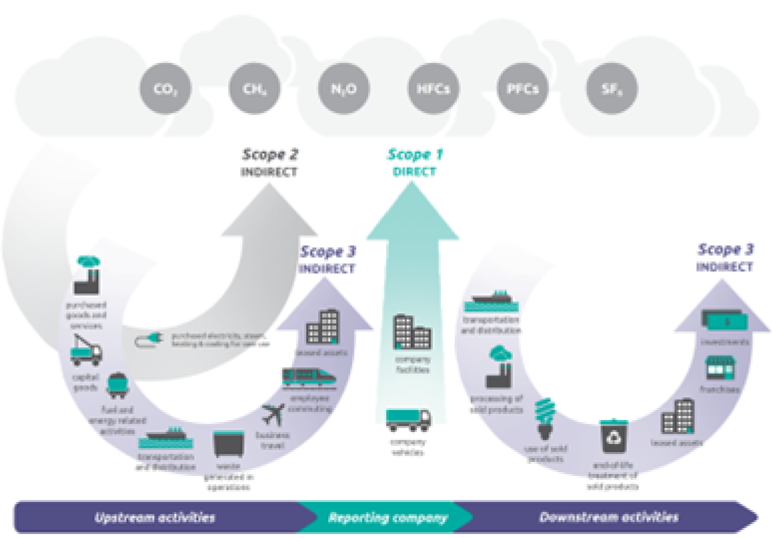
# 1. Introduction

Addressing climate change is one of the greatest challenges facing humanity. According to the World Meteorological Society[1], July 2023 was the hottest month on record, with extreme heat attributed to climate change and having adversely affected 6.5 billion people (i.e., 81% of the world population[2]). Climate science is clear: to avoid the worst social economic impacts of climate change and achieve sustainable development, global temperature rise needs to be limited to 1.5 °C above pre-industrial levels[3]. However, the Intergovernmental Panel on Climate Change (IPCC) has warned that global temperatures have already risen by at least 1.2 °C above pre-industrial levels in some parts of the world[4]. Humanity has a narrow and ever shrinking window of time to address this challenge by reducing global greenhouse gas (GHG) emissions by 45% by 2030 and reach Net Zero emissions by 2050 or earlier, if possible.

In broad terms, reaching Net Zero means reducing anthropogenic GHG emissions to as close to zero as possible and any remaining emissions, which are technically unfeasible to eliminate, should be removed from the atmosphere through natural or technological processes. The GHG Protocol Corporate Standard classifies GHG emissions into three 'scopes' as illustrated in Figure 1:

- Scope 1: Emissions from sources under direct operations control or ownership. For mobile communications networks, this includes emission resulting from onsite use of fossil fuels in backup generators or fleet fossil fuel consumption.
- Scope 2: Indirect emissions from the generation of purchased energy. This would include emissions resulting from the generation of electricity used to power mobile networks.
- Scope 3: All indirect emissions that occur in the value chain of an organization, both upstream and downstream from their company operations. This would include emissions from the use of products sold and business travel.

**Figure 1 Overview of GHG Protocol Corporate Standard scopes of emissions across the value chain (source:** WRI/WBCSD Corporate Value Chain (Scope 3) Accounting and Reporting Standard)




In an increasingly digital world where approximately 70 percent of the global population uses Information and Communications Technology (ICT) services, the total life cycle carbon footprint of ICT has remained stable at approximately 1.4 percent of total global GHG emissions. The mobile industry is a smaller subset of the overall ICT sector and is estimated to account for approximately 0.4% of the total global carbon emissions[5]. The mobile industry's impact on climate includes direct value chain emissions (Scope 1, 2 and 3), is primarily associated with the use of the mobile network and secondarily with the manufacturing and disposal[6] of hardware and devices.

Furthermore, the mobile industry has an indirect positive impact on climate, and the potential of ICT to enable de-carbonization of key industries and sectors has been estimated to enable up to a 15% reduction in global GHG emissions by 2030[7].

The ICT industry has aligned on a science-based pathway to reach Net Zero emissions, which was developed in collaboration with ICT industry groups. MNOs and manufacturers globally are increasing their commitments to reach Net Zero emissions, acting on emissions across their entire value chain. In 2023, telco industry organizations representing 46% of global connections have set science-based targets. The majority have committed to halve the GHG emissions identified in Scope 1-3[8], and 39% of MNOs have committed to reaching Net Zero emissions[9].

This paper is focused on presenting the key strategies and technologies to reduce direct emissions associated with the use of mobile communications and the de-carbonization potential therein. The strategies and technologies discussed in this paper are foundational to understanding the mobile industry's potential for enabling positive impacts for planet and society. The triple bottom line drivers for enabling these impacts and the de-carbonization of the 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 (U.S.), there is disparity between the various States in terms of school connectivity. Increasing the speed of broadband connectivity to match the highest levels available in the U.S. can result in a 5.5% increase in Gross Domestic Product (GDP) by 2025[10]. 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 NetZero goals.
- **Economic:** The estimated annual energy costs for running a mobile network falls around $25B[11], as MNO energy consumption constitutes between 20-40% of network operational expenditures (OPEX)[12]. With the recent energy crisis and increasing network energy use, these numbers are expected to be higher. This makes reducing energy consumption of mobile networks an economic and environmental imperative.

As previously stated, the majority of the operational emissions of the mobile industry 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 measures as well as switching to renewable or low carbon sources of energy to power mobile networks. Figure 2 shows some examples of potential actions based on the International Telecommunication Union (ITU) guidance towards Net Zero. 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. While application of circular economy principles is critical for the mobile industry to reach Net Zero, this aspect is not included within the scope of this paper.

Figure 2: De-carbonization measures towards Net Zero

**CATEGORIES:**

OPERATING ENERGY-EFFICIENT NETWORK

1. Multiple power saving features
2. Alternative energy supply
3. Consolidation and virtualization
4. Free cooling and location optimization

EFFICIENCY IN BUILDINGS AND SERVICES

5. Monitoring solutions for efficient buildings
6. Focus on energy conservation measures
7. Alternative mobility concepts
8. Videoconferencing and audioconferencing

ALTERNATIVE ENERGY

9. Self-production of renewable energies
10. Purchasing renewable energy the certificate of origin and PPA
11. Energy supply innovation

APPLICATION OF THE CIRCULAR ECONOMY PRINCIPLES

12. Eco-design of products and services
13. Reuse of network equipment
14. Optimizing the life cycle and end-of-life of customer products and services
15. Selling repairable products

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**Figure 2 – Decarbonization measures**
(source: [ITU-T L.1470])

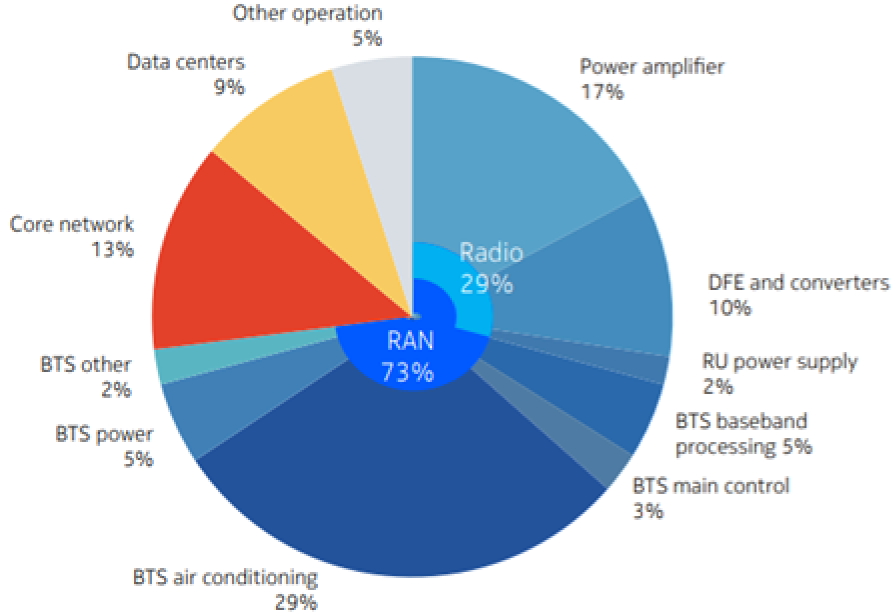
## 2. Technologies Driving Energy Efficiency in the RAN

Considering the imperative to reduce the environmental impact, mobile networks should minimize energy consumption, optimize energy utilization, and ultimatley minimize GHG emissions. It is crucial to recognize that approximately 95 percent of the product life cycle emissions associated with mobile radio networks occur during their operational use[13]. This realization underscores that the key to simultaneously curbing carbon emissions and reducing OPEX lies in the effective management of energy consumption during the mobile network operations.

Within the landscape of modern mobile networks, a substantial majority of energy is currently consumed within the Radio Access Network (RAN) domain. As delineated in Figure 3, an astonishing 73 percent of the total energy consumption is attributed to the RAN. Comparatively, the mobile core network and proprietary data centers account for 13% and 9% of the energy usage, respectively, with other operational components representing the remaining 5%. Notably, the energy share of data centers can be quite variable and largely depend on the operator configurations. Also 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 in the radio unit such as the power amplifier and digital frontend are key contributors to the overall RAN power consumption.

Notably, in recent years, reduction of base station energy consumption has been attained a) by moving the radio unit components as close as possible to the antenna, thus removing coax cables' RF signal losses; b) by developing RAN site components that can be used outdoors as much as possible, thus decreasing the need for air conditioning; and c) by developing 'single RAN' radio products supporting multiple bands and/or multiple RATs, allowing different types of RF sharing solutions[14]. These innovations inherently reduce the need of energy particularly for cooling. In general, the share of energy used for cooling can vary between 10% to 66% of the base station energy consumption. A share of 29% as shown in Figure 3 is typical of legacy RAN sites, which are indoor and equipped with active air conditioning. The less active air cooling is used and the more the radio units are placed outdoors the closer the share of energy consumption for cooling drops to 10%.

**Figure 3. Network Power Consumption Split by Domain. Source: Nokia Bell Labs[15] (based on NGMN data[16]).**



Given that the RAN domain constitutes the predominant consumer of energy within the mobile network, it is clear that the most effective path to bolstering the profitability of mobile networks and advancing toward climate-related targets hinges upon the minimization of energy consumption within the RAN. Consequently, the RAN is unequivocally the primary focus for scrutiny and intervention in energy-saving endeavors as elaborated upon in the subsequent subsections of this chapter.

In this context, this chapter aims to elaborate on technologies and strategies for attaining network energy savings and improved energy efficiency, focusing on the RAN domain. Generally, those technologies and strategies rely on the basic principle that adaptations of (radio) network parameters in response to traffic variations can be used to attain energy saving, and thus reduce GHG emissions. However, those adaptations should not negatively impact individual user Quality of Service (QoS) and Quality of Experience (QoE), and should be applied carefully depending on the number of active subscribers. However, in certain cases, a balance between end-user QoE and energy saving may be considered. Acknowledging the significance of artificial intelligence (AI) and machine learning (ML) in shaping modern network operations, this chapter also sheds light on innovative techniques that leverage AI/ML capabilities to enhance energy efficiency. These methodologies exhibit significant potential in advancing environmental sustainability goals and streamlining operational costs across the mobile network ecosystem.

The energy-saving considerations for end-user mobile devices, which contribute to the overall energy consumption of mobile networks, are beyond the scope of this paper. It's worth noting that the production and disposal of these devices have a much more substantial footprint impact than the operational usage stage[17]. However, even in this operational stage, continuous enhancements are being made in the latest generations of devices and radio technologies[18].

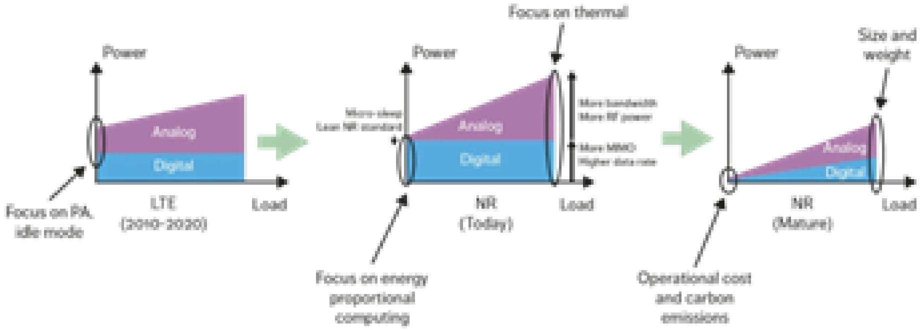
In the context of cellular network evolution, as networks transition from one generation to another, their energy consumption increasingly depends on the network load. Consequently, network traffic emerges as the primary driving force and a crucial parameter for optimizing network components, enabling adaptation of radio resources across time, frequency, space, and power domains in response to changes in traffic load. The key techniques that could be deployed in the RAN to substantially enhance energy efficiency are described in the following, which take int account the recent network energy-saving enhancements enabled by 3GPP 5G-Advanced[19,20,21,22].

## 2.1 Techniques in Time Domain

In the time domain, techniques such as micro-sleep were proposed to deactivate and reactivate power amplifiers (PAs) within microseconds, aiming to conserve energy during idle periods. These efforts proved beneficial in 4G LTE (Long Term Evolution).

Moreover, with 5G NR (New Radio), the physical layer underwent a leaner design, and the load dependence significantly increased. For example, the 5G NR design removed the always-on cell specific reference signaling of LTE, which has to be sent every 1ms, thus continuously interrupting cell sleep opportunities. Consequently, features like micro-sleep became substantially more effective in 5G NR networks. Some live networks have already observed the positive impact of these advancements. Further enhancements leveraging micro-sleep are introduced in 5G-Advanced such as cell discontinuous transmission (DTX), which enables the cell to omit certain transmissions during the cell OFF periods that otherwise would be required in legacy networks. The devices are informed about the OFF periods of the cell so that both the network and the device can save power[17,19].

Figure 4: The power consumption journey of the radio unit in the base station




Furthermore, 5G NR is designed for massive multiple-input multiple-output (MIMO) and supports wider bandwidths than LTE to deliver higher data rates and capacities. As such, the larger bandwidth and the higher number of antenna branches increased the peak power usage of analog components. Meanwhile, the digital processing time (which increased 320 times compared to LTE products) has increased the power consumption of digital components, as portrayed in Figure 4[23]. This calls for novel measures beyond turning on and off PAs in various domains, which is discussed next.

## 2.2 Techniques in Frequency Domain

In the frequency domain, there are several measures that can enable enhancing the leanness of the network to become more energy efficient. Essentially, as we transitioned from one wireless generation to the next, the waveform adopted (like the overall physical layer design) became more flexible and leaner. For instance, in 4G, the orthogonal frequency division multiplexing (OFDM) waveform was used because of its improved spectral efficiency and MIMO adoption. Then, in 5G, a flexible OFDM design was introduced with support for multiple subcarrier spacings, i.e., a flexible numerology scheme with a range of different subcarrier spacings, rather than one, to adapt to various frequency bands and use cases while allowing the coexistence of different subcarrier spacings.

The main challenge of the OFDM waveform is its high peak to average power ratio (PAPR), which gets aggravated for higher carrier frequencies. As wireless generations continue to progress, the PAPR phenomenon may get worse when using higher frequency bands. This is particularly harmful for the uplink and the energy efficiency of the device. Subsequently, in 5G-Advanced and 6G, the flexibility of the waveform should be further enhanced. This will not only enhance the energy efficiency of the system but also enable the coexistence of different waveforms that may serve different purposes (e.g., joint sensing and communication). For instance, at lower loads, there is not a need to multiplex multiple users across the frequency domain. For this case, one plausible solution is the adoption of single carrier waveforms to make the network energy consumption comparable to systems with narrower bandwidths[24]. Another solution for reducing PAPR is to reserve some tones aiming at reducing PAPR of the transmitted signal such that its distortion is minimized per given input operating point[8].

Additionally, it is important to leverage software capabilities that enhance the energy performance without the need to add more hardware[25]. One pathway would be carrier aggregation, which could expand the coverage by using lower frequencies and efficiently move data to higher bands, while leveraging cross-carrier scheduling capabilities. In 5G NR, carrier aggregation can expand mid-band coverage while leveraging the low-band, and then move data to higher bands that may be more energy efficient. It is noted that operating at higher bands implies an increase in the transmit power to compensate for the larger propagation losses. However, it typically benefits from a larger availability of spectrum and the use of massive MIMO capabilities, which increases the achieved spectral efficiency, and in turn energy efficiency.

In the future networks, the energy efficiency of the capacity layer can be further enhanced by reducing or omitting common channel transmissions such as Synchronization Signal Block (SSB) or System Information Block (SIB) using 5G-Advanced techniques such as SSB-less Secondary Cell operations or on-demand SSB/SIB1 operations. Furthermore, innovative solutions, such as spectrum sharing, enable single communication service providers to deploy new technologies on existing frequency bands/infrastructure. Such techniques enable the re-use of pre-deployed hardware and infrastructure without sacrificing performance and allow expanding the nationwide coverage while taming long-term sustainability and energy efficiency goals. For example, when introducing 6G, it could operate in the same carrier as 5G using fully flexible and dynamic 5G and 6G multi-RAT spectrum sharing (MRSS) technologies[26].

## 2.3 Techniques in Spatial Domain

In the context of spatial domain optimizations, the evolution of 5G and 5G-Advanced base stations represents a significant stride towards improved energy efficiency. These advanced stations are engineered to dynamically adapt the number of active spatial elements, such as antenna ports and antenna elements, allowing the deactivation of associated components such as the transmit unit, antenna panel, and the logical antenna ports. This adaptability is not merely a feature; it is an imperative aspect of modern telecommunications infrastructure geared towards energy conservation.

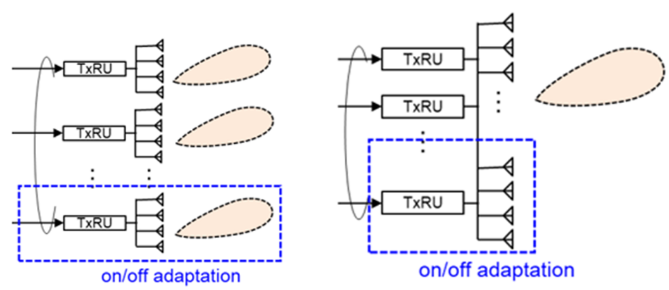
At the core of 5G NR technology lies massive MIMO, a foundational innovation lauded for its ability to deliver exceptional spectral efficiency and expansive coverage. In the realm of downlink transmissions, massive MIMO systems boast an abundance of spatial elements, including transceiver chains, antenna ports, and physical antenna elements. Remarkably, each of these spatial elements can be tethered to one or more PAs, collectively consuming a substantial 70% of the overall base station's power.

Therefore, in the quest for network energy efficiency, it becomes paramount for these base stations to possess the capability to judiciously activate or deactivate specific spatial elements. This adaptive capability plays a pivotal role in optimizing power consumption while maintaining network performance. The decision to adapt these spatial elements should be made based on a comprehensive assessment of factors such as traffic load and user radio conditions.

The precision with which spatial elements are adapted is crucial to ensuring minimal disruption to user experiences. For instance, during periods of high-traffic load, it is advisable to activate all available spatial elements to meet the traffic and QoE demands. Conversely, during low traffic periods, activating only a select subset of spatial elements, especially for users positioned favorably near the cell center, is a prudent approach.

Figure 5 illustrates two different implementations of spatial element adaptation at logical antenna port level and physical antenna element level, respectively. This nuanced approach to energy conservation signifies a transformative leap in the evolution of 5G and 5G-Advanced base stations, bolstering their sustainability and reinforcing their ability to deliver seamless, high-performance telecommunications services.

**Figure 5: Spatial domain adaptation types (R1-2301505, Feb 2023)**




Type 1 adaptation (logical antenna port level)
Type 2 adaptation (physical antenna element level)

## 2.4 Techniques in Power Domain

PAs operate at their highest level of power efficiency when they work near their compression or saturation point. However, this efficiency comes at the cost of non-linear distortion introduced to the transmitted signal, which may lead to degradation in the throughput of the communication link. To avoid this issue, the typical PA operating point is set to be well below its compression point such that the PA response is kept linear. That, in turn, leads to lower PA power efficiency. Lower efficiency means that more input power is needed to provide a fixed level of RF output power. The power delta between the PA compression point and actual operating point is also referred to as "back-off". The power consumption of PAs is expected to increase as the network moves towards higher carrier frequencies, both because of the usage of more antenna elements as well as poorer PA efficiency at the higher frequencies. Therefore, it is important to develop techniques to optimize PA efficiency and reduce network power consumption. In particular, the techniques should mitigate the non-linear impairments introduced by the PA to enable PAs work with smaller back-off.

Digital Pre-Distortion (DPD) has been widely implemented for improving PA energy efficiency. Essentially, DPD is a technique pre-distorting the transmitted signal such that the combined impact of this pre-distortion and the PA correction circuitry results in a linear signal. The required pre-distortion function is typically learned by an internal RF loopback chain used to feedback the PA output signal back to the digital processor. The feedback signal is used to learn the PA non-linearity model and calculate the proper inverse distortion. DPD enables operating the PA closer to its saturation point while maintaining good linearity. With the introduction of beamforming systems, based on multiple antenna elements, calculation of the DPD has become much more challenging. The non-linearity as seen by the receiver is a composite distortion coming from all PA elements and might also be impacted from cross coupling distortion between the PAs. Maintaining a feedback path per antenna and creating a separate DPD correction per antenna is costly in die area of the circuit and in power consumption. In addition, individual antenna element calibration might not capture mutual coupling effects.

A more suitable solution is to use over-the-air training and have the receiver estimate and feedback the composite non-linearity. The DPD functionality at the transmitter is calculated per MIMO layer and not per Tx antenna. This solution can enable a much cheaper DPD solution in power and size. Furthermore, instead of having DPD at the transmitter, the PA power efficiency can be improved by enabling non-linear processing at the receiver side to mitigate the transmitter PA non-linearity. However, the overall complexity of such solutions remains quite high.

## 2.5 The Role of AI/ML as a Key Enabler in Sustainability

The use of AI and ML in the field of telecommunications is playing a pivotal role in enhancing energy efficiency within network infrastructure. As highlighted in the "2022 Breaking the Energy Curve" report by Ericsson[27], the energy consumption of mobile networks has been on the rise with each new generation. This trend is expected to continue, particularly with the introduction of 5G and the growing demand for site densification to support emerging use cases. Therefore, the integration of AI and ML technologies is vital in helping the telecom industry achieve its Net Zero goals and reduce energy consumption. The main applications of AI/ML tools for network energy reduction include the following:

- **Precise Network Planning:** AI/ML plays a pivotal role in enhancing energy efficiency in network design and optimization services. By utilizing AI/ML models, MNOs gain a deeper understanding of their networks and users, enabling them to design and deploy network resources with precision. This ensures that energy-efficient solutions are tailored to the unique needs of each radio site, optimizing network deployment to align with customer demand.
- **Dynamic Network Optimization and Energy Management:** Network optimization services are pivotal for achieving improved energy efficiency. These services utilize AI/ML-driven predictions and energy-saving functionalities to make real-time decisions that effectively manage resources and reduce energy consumption during periods of low network usage. AI/ML algorithms dynamically allocate resources, such as frequency bands within the RAN to match actual demand, resulting in significant energy savings. Given that the RAN is a substantial energy consumer in mobile networks, these optimization techniques yield significant benefits[28,29].
- **Risk Management and Insight:** MNOs have at times approached the activation of energy-saving features with caution, mindful of potential impacts on network performance and customer experience. However, AI consultancy services offer MNOs a valuable opportunity to thoroughly evaluate the effects of these features without making immediate changes to their operational networks. This is accomplished by creating a digital twin of the network environment and implementing reinforcement learning techniques, allowing MNOs to discover the most advantageous settings for optimizing energy efficiency. This proactive approach not only mitigates potential risks but also fosters greater confidence in the effectiveness of AI-driven solutions.
- **Sustainability Through Hybrid Power Solutions:** AI/ML frameworks, in conjunction with data such as weather forecasts and energy grid information, optimize energy efficiency when hybrid power solutions are introduced. MNOs can determine when to use the grid, solar power, or wind power, and when to charge or discharge batteries from variable power sources. This optimization ensures that the network is prepared to efficiently meet anticipated demand, leading to potential cost savings while contributing to sustainability goals.
- **Benchmarking for Sustainability:** Benchmarking practices are essential for MNOs to evaluate the quality of their service and sustainability efforts. AI technology extends beyond energy efficiency

> and offers additional benefits to network sustainability. Virtual drive tests, based on AI predictions using real network data, replace manual benchmarking practices that involve extensive driving, which reduces costs, traffic, emissions, and safety risks. AI/ML-powered benchmarking provides more accurate and insightful results by measuring network performance where users are located, including inside homes, offices, and buildings. This not only improves sustainability by reducing environmental impact but also enhances the overall efficiency and reliability of the network.

As previously mentioned, the industry is actively delving into the utilization of AI/ML capabilities and algorithms for enhancing energy-saving solutions across multiple phases of network planning and operations. Moreover, 3GPP enablers are now coming into play, specifically targeting the seamless integration of data and data analytics within the AI/ML cycle. These enablers facilitate the necessary signaling for AI/ML algorithms. For instance, this data can serve as input for predicting cell loads and states, or it can provide valuable feedback to refine predictions. This, in turn, enables the implementation of tailored energy-saving measures, such as traffic offloading, and the dynamic activation of sleep modes, among other strategies[30,31].

# 3. System Architecture Solutions for Energy Efficiency

As previously highlighted, the RAN consumes by far the largest amount of energy in the entire mobile network, and, therefore, is the primary domain to scrutinize to achieve energy saving. As a first objective, the system architecture and its optimizations for energy saving should facilitate efficient energy use and energy saving in the RAN. However, it is also necessary to optimize the end-to-end network energy consumption with the aim of improving the overall energy efficiency of the network. Thus, as a second objective, measures and optimizations for improved energy efficiency of the core network infrastructure are also needed.

In general, core network modernization and the introduction of the cloud-native 5G core (5GC) enable the use of energy-optimized cloud platforms and edge components, whose energy consumption is scalable with the load (see also Section 5.3). Furthermore, there are well defined Operation, Administration, and Maintenance (OAM) mechanisms for managing and orchestrating the activation and deactivation of RAN energy-saving features such as capacity cell switch off as well as the powering up and down of a network function, e.g., 3GPP TS 28.310. Such mechanisms for activation and deactivation are based on the energy-saving state of the network element or network function, also defined in 3GPP TS 28.310, and indicating when they are powered down. For example, traffic offloading may be triggered based on the decision of a cell to enter the energy-saving state.

Despite the existing standards, enablers would allow them to also power-down network functions. Currently, core networks (including the 5GC and the edge components) typically operate in peak capacity mode (in which full capacity is always enabled) as there has been no concern with energy efficiency in the core network. As a result, the current procedures do not take the energy aspects into account, nor are they designed to operate optimally in energy-saving state and in energy-efficiency mode.

The current 5GC implementations based on a micro-services cloud-native architecture can make load-dependent adjustments. With the increasing attention to end-to-end (E2E) energy-saving, several energy-efficiency enhancements are envisioned for the 5GC targeting both above-mentioned objectives. Examples of the anticipated measures and enhancements that are being considered by the 3GPP for 5G-Advanced and beyond include the following[32 33 34 35 36]:

- Defining enablers for energy-saving mechanisms applied to the 5GC and network slicing. This includes switching off some micro-services during low load for energy saving or even larger network functions (e.g., edge User Plane Functions (UPFs) deployed at campus premises), but also selecting Network Functions (NFs) based on their energy efficiency and load state to save energy more globally. These mechanisms can also be introduced on a per-network slice manner.
- Enabling estimation, and report of energy consumption (including the ratio of renewable energy), energy efficiency (e.g., energy consumption per unit of data volume) as well as carbon emissions of network functions in the cloud environment, where the virtualized NFs (VNFs) or micro-services are composed of scalable virtual compute instances. Control loops that optimize for shutdown and restart of services can be defined with the help of AI/ML or statistical procedures to prevent introduction of processes that end up using more energy than they save. To avoid unnecessary service interruptions on shutdown, it may be necessary to perform an in-service migration of currently operational customer processes away from the entity being shut down.
- Enabling energy efficiency as service criteria (i.e., as a service characteristic)[37], including enabling energy consumption exposure (e.g., at network slice level, subscriber level, Non-Public Network (NPN) customer level) and enforcement of a maximum energy credit limit as policy for best effort services. In this latter case, subscription policies can define an upper bound on the aggregate quantity of energy consumption by the 5G system to provide services to a specific subscriber, e.g., kilowatt hours.

- Enhancements for dynamic energy-saving operations to adapt the services / applications to the network conditions including changing energy state at predefined times, loads, etc.
- Supporting dynamic pooling of RAN resources among operators for energy saving, beyond the traditional static network sharing agreements. This would allow an operator to occasionally serve subscribers from other operators that are usually providing communication service via their own network infrastructure over the same geographical area, but which temporarily can shut down (part of) their own infrastructure for energy saving. Such pooling of the communication service can be achieved, e.g., via RAN sharing techniques (including indirect network sharing) or national roaming agreements wherever applicable, and they apply to coverage and/or capacity layers. Over a specific geographic area, operators could thus alternate energy savings, each of them temporarily providing service to the other subscribers.

In addition to energy saving, the need to minimize carbon footprint has also increased the focus to utilize alternative and renewable energy sources, i.e., green energy. However, the current system architecture standards fell short at providing criteria related to the energy source type (i.e., considering the carbon emission intensity of the energy source). Therefore, it would be beneficial to include such energy related criteria when designing future networks to allow MNOs to deploy policies based on energy sources.

## 3.1 Network Slicing

End-to-end network slicing has attracted much interest from operators because the technique becomes a useful tool in tackling both industry verticals and special service characteristics associated with throughput, latency, mobility, and reliability. An E2E slice comprises RAN, mobile core, and transport and provides inter-slice security and no-shared-fate. Today, RAN capabilities in network slicing are provided by schedulers that operate on different classes of service and on the same numerology. In the future, it may be possible to mix different numerologies in the same scheduler. The Bandwidth Parts (BWP) mechanism allows for this. Multiple network domains are involved in E2E slicing, and each slice will adapt to the unique requirements of the use cases supported, so network slicing will require special attention for GHG emission control.

Key to controlling GHG emissions in the slicing architecture is ensuring that each endpoint corresponding to a use case class is allocated to the lowest consumption power class consistent with the use case requirements. A slice and its subdomains (RAN, transport, core, virtualization platform) can be monitored for network and UE power consumption and, through statistical learning methods, be trained to reduce power utilization by classifying endpoints into a power class while maintaining the defining characteristics of the slice. RAN, core and transport considerations apply. Methods described elsewhere apply and can recommend specific use cases to build on a slice based on service characteristics and GHG emission considerations.

While network slicing is still emerging, the concept has significant attractiveness. It is worthwhile for both vendors and operators to use this new technology to begin developing green strategies.

# 4. Deployment and Architecture Strategies for Network Energy Saving

In this chapter, we discuss how network deployment options, including small cell densification and indoor solutions, can help improve energy efficiency. Furthermore, we look at key system architecture enablers, such as virtualization and Open RAN, in the context of sustainability and power efficiency. We also look into RAN sharing and shared infrastructure as ways to increase sustainability and energy efficiency in mobile networks while presenting opportunities and challenges that the industry needs to overcome with these approaches.

To better understand the shared infrastructure options, we first need to place infrastructure concepts in the context of the typical wireless network as sharing can happen in various places.

- A wireless network consists of a mobile core, a transport network (fiber backhaul), RAN, antenna, and vertical structure. The mobile core is unique to each operator and provides multiple functionalities such as mobility management, authentication, session management, QoS, etc.
- The transport network, or backhaul, is required to connect the RAN to the mobile core. This component in the wireless network can be shared and provided by a third party.
- The RAN comes in various shapes and sizes. It can be a fully integrated single unit, it can be separated out to have the baseband processing in one location and the radio unit near the antenna, it can have the antenna integrated with the radio unit, and it can even have the baseband processing divided out in a central unit and a distributed unit. Regardless of the RAN architecture, the U.S. network operators deploy these independently and do not share in the outdoor networks.
- The antenna, if separate from the radio, is typically dedicated in macro deployments, but often it is shared in outdoor small cell deployments.
- Finally, there needs to be some vertical infrastructure (tower or building) where the antenna can be mounted to optimize the coverage area. The vertical infrastructure is often shared to minimize cost and quantity.

Deployment strategies for wireless networks consider several factors, including (but not limited to) cost, environmental, regulatory and social considerations. Energy savings is only one factor that plays into the overall selection of an approach.

## 4.1 Small Cell Densification

The adoption of smaller cells represents an architectural trend that prioritizes energy-efficient network designs, specifically through the deployment of small cells or multi-TRP (transmission reception point) base stations with remote radio heads. Small cells operate at significantly lower power levels compared to traditional macro base stations. Due to the considerably lower power required for optical link transmission compared to wireless link transmission, small cells exhibit reduced transmission power for a given data rate in comparison to macro cells.

Several small cell products on the market have power consumption requirements in the 100 W range. At these power levels it may be possible to use alternative energy sources such as local solar panels and battery backup systems. Most small cells are also passively cooled thereby reducing the overall ICT energy footprint due to cooling (see Figure 3).

Densification of network infrastructure introduces innovative architectural possibilities, including cell-free massive MIMO[38] In this paradigm, users are not tied to a specific cell but instead served by multiple surrounding antennas. In a densely packed network, users find themselves encircled by antennas rather than being dispersed around them, as is typically the case. This approach eliminates the need for user association with specific radio cells, and user-related information is centrally managed, potentially within the edge cloud[39].

In a heterogenous network architecture with capacity and coverage cells, the advantage of incorporating small cells lies in the small cell's ability to efficiently enter deep sleep states and quickly return to an active state compared to macro cells. This lower transition time not only enhances energy efficiency but also bolsters overall network performance, allowing for swift toggling between sleep and active modes. In the case where there is overlapping coverage from macro cells it is possible to place these small cells into deep sleep during low traffic period such as during the night (which further allows the possibility of using solar panels)

No one size fits all, due to market conditions and requirements, load conditions, and other factors. In the case of urban and dense markets, it may be greener to have more base stations. On the other hand, network densification isn't always economically sustainable, so small cell separation to prevent interference and maintaining quality during handovers can pose challenges.

Additionally, managing the increased handover rate in a dense network presents a significant challenge that requires careful network planning and optimization[40] Densification necessitates the deployment of many small cells, which can pose deployment challenges, including societal acceptance. Identifying locations and high acquisition costs complicate planning. Extreme densification raises operational expenses and worsens the carbon footprint[41].

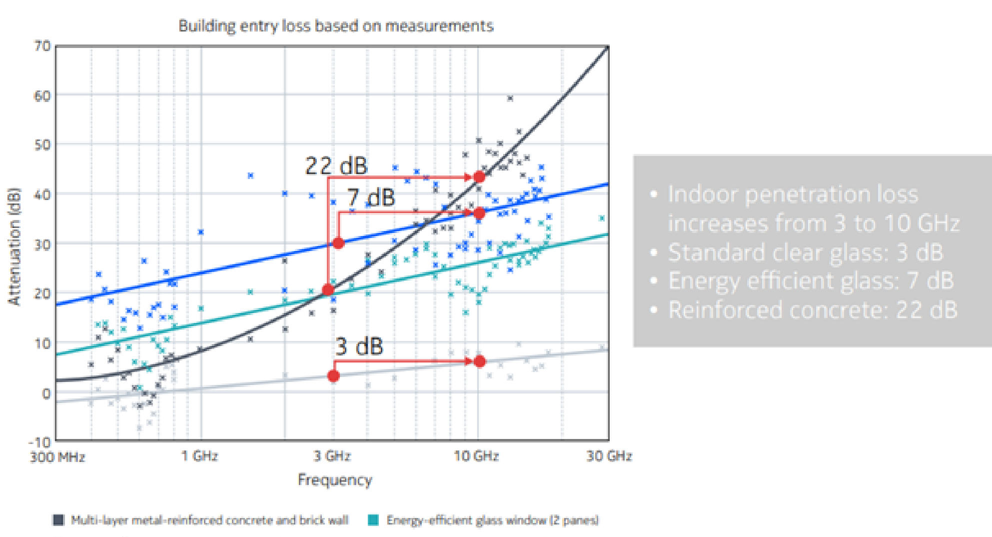
Therefore, it's crucial for operators to thoroughly comprehend the deployment scenario and strategize the market and deployment, assessing whether densification is advantageous or not.

## 4.2 Indoor 5G Deployments

In-building commercial wireless coverage is critically important for high satisfaction of mobile users. It is commonly estimated that 80% of cellular traffic originates or terminates indoors, and in-building penetration from the outdoors macro is only getting more challenging with the new 5G mid-band frequencies (2.5 – 4.0 GHz), and more buildings are employing low emissivity or Low-E glass to address energy conservation needs. As a result, MNOs have been deploying inbuilding wireless (IBW) systems for many years.

Figure 6 illustrates penetration loss measurements as a function of frequency for different building materials[42]:

**Figure 6 Penetration loss measurements as a function of frequency for different building materials[43].**

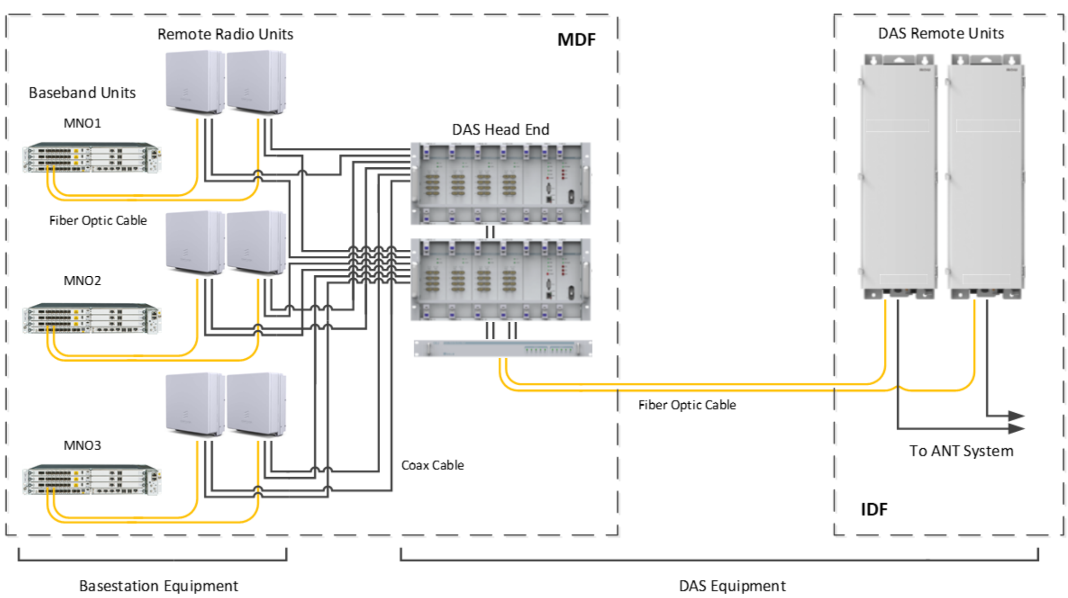


The demand for improved IBW performance appears to only increase as wireless data consumption continues to grow. The higher throughput capability of new 5G frequency bands combined with increased building penetration will require the deployment of IBW systems. Fortunately, the technology has evolved to a point where both performance and efficiency has been optimized to make for high quality, sustainable IBW networks. Today, operators can choose from a menu of options that include Distributed Antenna System (DAS) solutions, small cells (SC), and Wi-Fi with MNO authentication. All three approaches result in a complement of voice and data services. Moreover, for each method, there is the potential for network sharing resulting in a beneficial architecture applicable to IBW. Details of three approaches to network sharing is discussed below.

### 4.2.1 DAS Solutions

The DAS solutions were originally designed to take the base station passband signals to/from the RRUs ("radio heads") and distribute them throughout the building via fiber optic cable. An advantage these systems have is that they can transport multiple non-overlapping carriers from different MNOs simply by combining them. This is shown in Figure 7. Initially, each MNO wished to minimize sharing of active devices, but over time, all became comfortable with sharing DAS components as cost and aesthetic demands from the building owners and tenants increased.

**Figure 7: Dual band 2x2 MIMO DAS deployment. In this case, the system is hosting three different MNOs.**

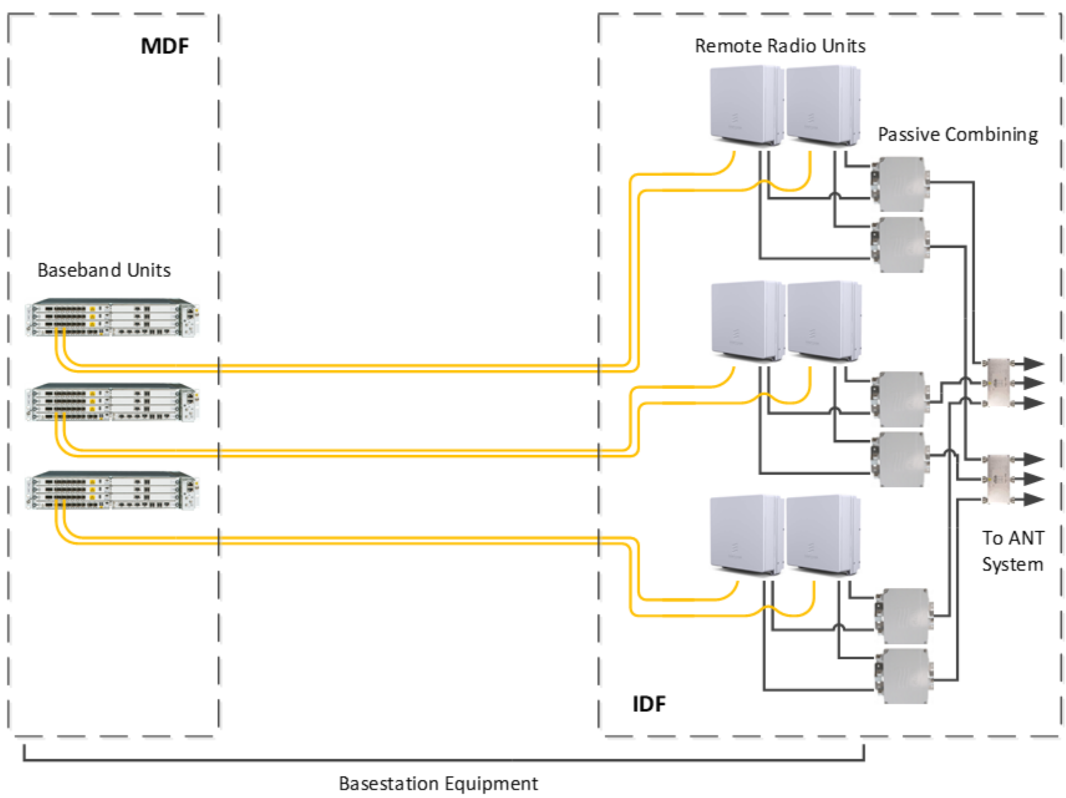



Unfortunately, some DAS deployments can consume significant power and be very inefficient. This is the case where the Remote Radio Units (RRUs) deployed by operators transmit between 5W and 40W per antenna port, only to be attenuated down in the DAS Head End to 1mW or less prior to conversion from RF energy to light for transmission through fiber optic cable to the DAS Remote Units (RUs). Individually, both the RRUs and DAS RUs are extremely inefficient due to their need to be highly linear (minimal noise or interference). The simple example shown above, with 5W RRUs from three MNOs, two DAS RUs for 2X2 MIMO operation, and two frequency bands, the total system consumes about 1500W on average, or 36kWh per day. This does not include the additional cooling requirements that may need to be provisioned in the MDF (main distribution frame) and IDF (intermediate distribution frame) rooms, respectively.

There have been some improvements to the DAS architecture to improve performance and efficiency. For example, RAN vendors developed RUs specifically for the purpose of feeding a DAS, so they have very low transmit power, requiring less input power, output attenuation, and cooling. Also, DAS vendors developed lower power RUs to be integrated with the antennas, which eliminates the output power loss through the coax distribution and additional power and cooling in the IDF rooms. These new developments have not been universally adopted because MNOs will often use the RRU equipment they have in inventory rather than purchasing new low power RRUs, and low power DAS RUs with integrated antennas distributed throughout a building can significantly increase the cost of the DAS solution.

The preferred IBW architecture shifted to be more power efficient, lower in cost, and higher performing. By removing the active DAS equipment, the RRU power no longer needed to be attenuated down and turned into heat in the MDF room. The dedicated Distributed RAN (DRAN) architecture moves the specialized low power RRUs closer to the antennas, combines the RRU outputs, and directly distributes them to the antennas as shown below.

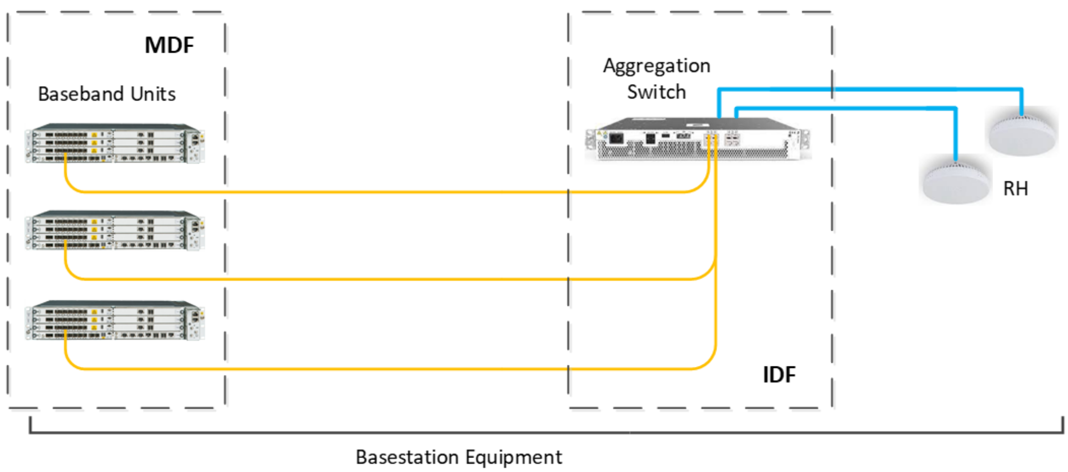
**Figure 8: Dual band 2x2 MIMO Dedicated DRAN DAS deployment. In this case, the system is hosting three different MNOs.**




The downside of a Dedicated DRAN deployment is that the RRUs have moved from the MDF room to the IDF rooms, which are typically smaller and less well provisioned for power and cooling. For this example, with 5W, 2X2 MIMO RRUs from three MNOs and two frequency bands, the total system consumes roughly 900W on average, or 21.6kWh per day, which amounts to a 40% reduction over the typical DAS deployment described above.

The next logical step in the evolution towards the ideal IBW system is to reduce the number of medium to high power RRUs in the deployment to decrease the input power and cooling required. Consequently, a system has been developed that allows the MNOs to share the RRUs and thus minimize redundant radio equipment. The key element in the architecture is the specialized “Aggregation Switch” shown in Figure 9 below, which performs the functions of the fronthaul interface and a set of sophisticated multiplexing functions combining several streams from different baseband units typically being deployed by operators using CPRI or eCPRI format. The subsequent radio heads (RH) are the only frequency dependent components throughout the solution which enables the ability to stay in the digital domain all the way to the edge bringing many benefits such as minimizing the distance between the RF front end and the UEs (low UE TX power that leads to minimizing UL interference and longer battery life) and very low power consumption (10s of watts vs 100s of watts for active DAS remotes).

**Figure 9: Typical dual band2x2 MIMO shared DRAN deployment architecture**




The shared DRAN architecture has multiple advantages. First, the BBUs and Aggregation Switch are digital units, so they do not require much space, power, or cooling. Second, the radios are shared by each of the MNOs, which minimize space, power, and cost. Third, there is no passive RF infrastructure in this architecture, such as coaxial cable, so it maximizes efficiency and performance. For this example, with eight RHs (typically covering about 50k sq. ft), 2X2 MIMO, three MNOs, and two frequency bands, the total system consumes roughly 600W on average, or 14.4kWh per day, which amounts to a 60% reduction over the typical DAS deployment and a 33% reduction over the typical dedicated DRAN deployment described above.

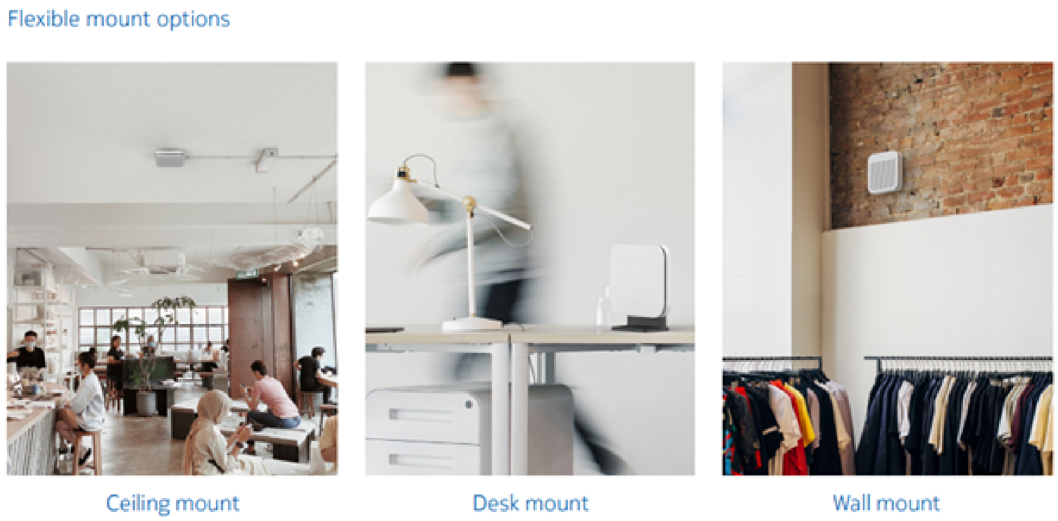
### 4.2.2 Small Cell Solutions

Small cells, (sometimes called “picocells”) are also an option for IBW. These are unobtrusive devices deployed in ceilings and connected via fiber or Ethernet to a baseband controller. These SCs typically would use 2x2 or 4x4 MIMO as well as operate on the full mid-band spectrum. Multiple frequency bands are available from vendors and mid-band TDD support for 5G solutions are available today. A neutral host solution can be supported in one of two ways. First, MOCN (Multi-Operator Core Networks) deployed from a centralized unit can provide backhaul interfaces into the mobile cores for each tenant operator. Second, compact mobile cores can be deployed on-premises with roaming interfaces into the multiple tenants. In both approaches, it is the baseband controller (scheduler) that oversees allocating resources to each tenant. VoNR can be supported over mid-band TDD indoors.

Indoor small cells represent a good choice for delivering a scalable solution to ensure uninterrupted indoor coverage. Furthermore, these radios are small and discreet, making it easy to deploy and the support of neutral hosting and multi-operator scenarios making this solution a natural choice for network operators, neutral hosts and TowerCos alike[44].

The ability to use 5G anywhere depends on a 5G macro network complemented by 5G small cell solutions. The physical design of the product is important consideration with an aesthetically designed product that can be easily mounted on walls, desks, or ceilings according to consumer preference, supports users to customize their deployment, and encourages product adoption[45].

**Figure 10 Examples of flexible mounting options with small cell solutions[46].**




Furthermore, with the advancement of 5G use cases such as Augmented Reality and Virtual Reality (AR/VR) to enhance the shopping experience requires greater bandwidth indoors as well as seamless connectivity. For smaller stand-alone shops like boutiques and cafes, femtocells would be a more suitable choice, whereas DAS and picocell solutions are cost-effective for larger spaces like malls[47]. With future ready modular design, these solutions are effective in providing reliable service and helps to plan efficient CAPEX investments.

Small cells operate at much lower transmission power than macro cells, resulting in significantly lower power consumption. However, covering a building with just small cells requires a larger number of units as their coverage area is smaller. This increased deployment leads to higher backhaul costs. Nevertheless, in the broader perspective, they emerge as a more suitable alternative for addressing localized traffic demands.

### 4.2.3 Wi-Fi with MNO Authentication

Wi-Fi is also a possible solution for indoor coverage for an operator. Indoor carpeted spaces already deploy Wi-Fi and so the power consumption is already within the power envelope for the indoor facility. For a network sharing architecture, the key is to ensure that Wi-Fi users authenticate with the 5G network of the MNO. Several comprehensive authentication federations have emerged to support multiple tenants on the Wi-Fi network including OpenRoaming, an initiative from the Wireless Broadband Association[48]. Authentication federations allow multiple MNOs to be supported on the same Wi-Fi federated APN or, an exclusive APN can be defined. Thus, a Wi-Fi environment can be transformed into a neutral host environment.

Several considerations apply to Wi-Fi deployments:

- A tenant may be concerned about capacity in their Wi-Fi environment and may be unwilling to share capacity, even for revenue, with a third party. In this case, separate spectrum is required, and this would drive the need for a cellular IBW solution distinct from Wi-Fi. This concern is becoming less so because of the introduction of Wi-Fi 6 and Wi-Fi 6E based on the 802.11ax standard.

- MNO voice over IP (VoIP) can be supported over Wi-Fi in the conventional way (e.g., with an ePDG or an N3IWF into an IMS) or it can be deployed on a cellular low-band with good outdoor-indoor performance. The voice solution does require premises-initiated outgoing IPsec tunnels which some enterprises suppress as a mechanism to control leakage to the outside of sensitive data, but this problem can easily be addressed by mapping the federation APN to a VLAN with the correct ACLs.
- Data session service continuity may be an issue for some mobile apps that rely on bindings to an IP address when the user moves between indoor Wi-Fi and outdoor macro-cellular as the IP address will change. For VoIP, the concern can be mitigated if the operator can ensure a common session anchor for indoors and outdoors.

The Wi-Fi solution for indoors is attractive in that it leverages well understood indoor technology (Wi-Fi) that is more than likely already deployed for sound business reasons and therefore has a well-known energy consumption envelope. It is relatively simple to implement on existing Wi-Fi deployments.

There is a compelling case to be made that new carpeted space deployments will deploy Wi-Fi and its newest version (Wi-Fi 6/6E and 802.11ax). A triband access point supporting 2.4 GHz, 5 GHz, and 6 GHz will consume about 35 – 30 W[49] and provide service gigabit for an average of 277 sq-m of carpeted space. (See endnotes for example[50].)

## 4.3 RAN Sharing and Shared Infrastructure

### 4.3.1 Introduction

In this section we discuss the concept of RAN sharing and how it can be used to effectively reduce the energy consumption footprint of mobile networks. From Section 3, we discussed how RAN techniques can lead to improvement in energy efficiency, however additional – and some would say even greater – improvements can be obtained by utilizing RAN sharing.

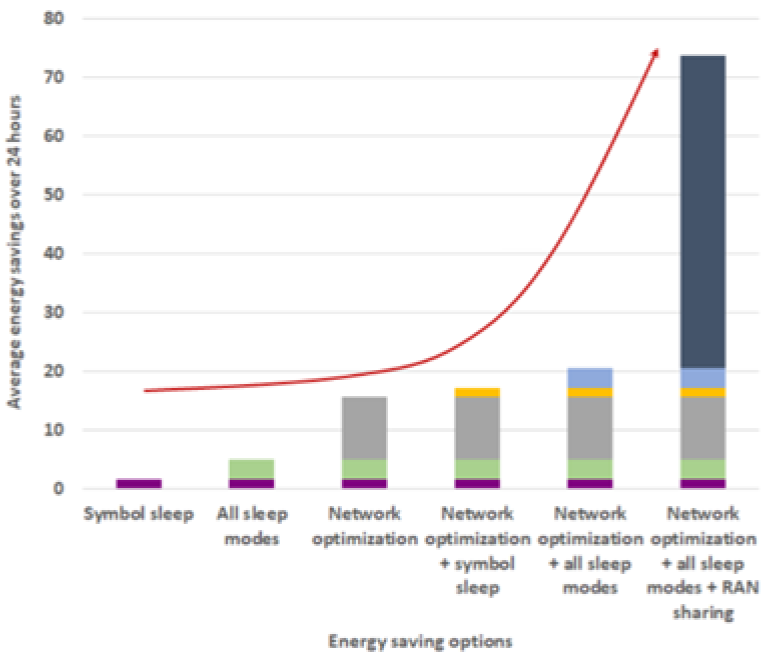
In February 2023, the Global Systems for Mobile Communications Association (GSMA) published a paper, “5G Network Co-Construction and Sharing Guide Whitepaper”[51] where it stated:

“By December 2022, China Telecom and China Unicom had deployed about 1,000,000 base stations, accounting for more than 40% of all 5G base stations around the world and built the world’s first and largest 5G SA shared network, realizing large-scale industrial applications. In addition, the sharing of 4G RANs between the two operators was promoted, saving over USD 40 billion in network construction, and reducing network operations costs by USD 4 billion, electricity usage by more than 10 billion kWh, and carbon emissions by 10 million tons per year.”

Two of the largest European operators, Vodafone and Orange, have had RAN sharing agreements since 2006[52]. In 2019, Nick Read, Chief Executive of Vodafone, said, “These network sharing agreements mean we can provide a better service to customers, help us to address coverage requirements faster and more efficiently and also reduce the industry’s environmental impact.” Vodafone and Orange continue to look for technological advancements in conjunction with RAN sharing to reduce energy consumption. In October 2023, they successfully deployed a shared network in Romania with an Open RAN solution using the concepts described in the below section “Specifications and Enablers”[53].

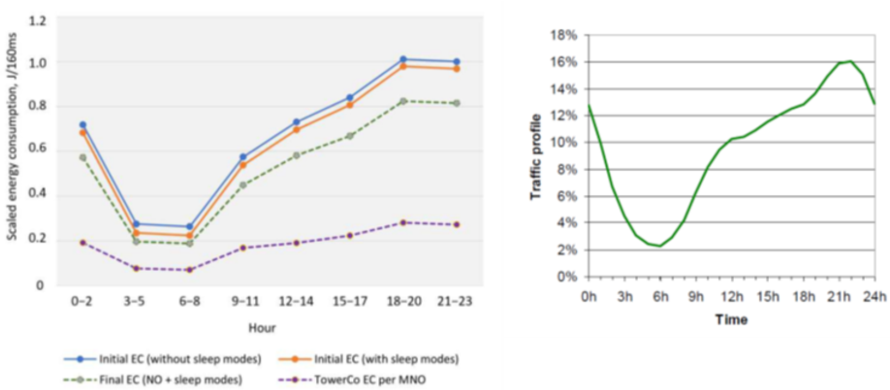
In another study[54], operators using network optimization (resource allocation/usage optimization) and energy-saving features in the RAN (such as sleep functions at the symbol, TTI, antenna and cell level) could achieve a 20% energy efficiency gain. However, when including RAN sharing, a 70% reduction of energy consumption could be achieved in the investigated scenario and under the considered assumptions (see endnotes[55]); that is significantly larger than all the other techniques put together.

**Figure 11: Comparison of different energy saving feature options including RAN sharing, Source: [S2]**




The study looked at energy usage throughout a 24-hour period where user traffic levels varied, and regardless of load on the networks there were always significant energy savings compared to RAN techniques or enhancements alone.

**Figure 12: Energy consumption (left) and traffic profile (right) over the 24-hour period, Source: [S2]**




| t | α(t) | t | α(t) |
|---|---|---|---|
| 0h | 13% | 13h | 10% |
| 1h | 10% | 14h | 11% |
| 2h | 7% | 15h | 12% |
| 3h | 4% | 16h | 12% |
| 4h | 3% | 17h | 12% |
| 5h | 2% | 18h | 13% |
| 6h | 2% | 19h | 14% |
| 7h | 3% | 20h | 15% |
| 8h | 4% | 21h | 16% |
| 9h | 6% | 22h | 16% |
| 10h | 8% | 23h | 15% |
| 11h | 9% | 24h | 13% |
| 12h | 10% | | |

Various governments, national regulator authorities (NRAs) as well as industry bodies have presented their position related to the benefits (including energy efficiency/reduction and environmental factors) of various RAN sharing techniques.

BEREC (The Body of European Regulators for Electronic Communications) have stated that there are potential spectral efficiency benefits as well as environmental benefits including reduced energy consumption, and mitigating citizens' concerns over base station radiation[56]. In another survey of National Regulators, there was a general opinion that RAN sharing decreases energy consumption and lowers the carbon footprint of the electronic communications sector[57]. The BEREC also commissioned an external study and one of the key findings was that more energy-efficient technologies (such as those in section 3 of this paper) and network sharing could reduce energy consumption and associated GHG emissions[58].

The ITU, the United Nations specialized agency for ICT, comprising of 193 Member Nation States, 900+ organization and 20000+ professionals, passed a resolution to mitigate climate change and that one of the top considerations was "that network infrastructure sharing may reduce energy consumption"[59].

The GSMA, with over 800-member MNOs, have made it a public policy that infrastructure sharing is in the interests of society, as a whole, and has the potential to reduce the carbon footprint of mobile networks[60]. The GSMA also concluded that by operators sharing infrastructure, a direct saving in energy consumption and reduction the operator's environmental impact would be possible[61]. As recent as February 2023, the GSMA stated in a whitepaper[62]: "Co-construction and sharing can dramatically decrease the number of nodes deployed in a network, improve the utilization rate of nodes, and provide more services with increased social and economic benefits without increasing energy consumption, thereby effectively reducing network power consumption and promoting green and innovative development."

All these organizations see the merit of RAN sharing to reduce energy consumption and achieve environmental sustainability. However it is up to the reader, their organizations and governments to further study and promote RAN sharing as a viable sustainability model via the use of voluntary, commercial, and/or regulator mandated agreements.

Reflecting on the current state of the US wireless network deployment model, everything is being shared except for the mobile core and the RAN. Some access facing elements of the core network can be shared but others are preferred to be dedicated to the operator (session anchor, session management, subscriber database, BSS, etc.). Alternatively, the RAN provides a great opportunity for sharing. If the remote radio unit (RRU) is separated from the baseband unit (BBU), operators can independently deploy their own BBU, which can be customized for their specific performance metrics. On the other hand, the RRU has standard characteristics that are not typically unique from one operator to the next. Its main function is to broadcast the transmit signal provided by the BBU and receive the end-user signal which is sent back to the BBU for processing. In addition, thousands of RRUs need to be deployed to provide ubiquitous coverage in any geographic area, and the RRU is the most power consuming and inefficient component in the wireless network.

The authors understand that there are auxiliary power systems, transport/backhaul systems and cooling systems and that these systems contribute to the total energy consumption. However, it is expected that every unit of energy saved by the RAN equipment will translate to additional savings on these auxiliary systems due to reduced waste heat, consolidation of equipment, and reduction of "fixed" energy usage to just keep these systems online.

In the rest of this section, we first look at the existing specifications as well as the number of enablers that make RAN sharing a viable strategy for achieving more energy efficient and sustainable mobile networks.

Secondly, we look at a use case of RAN sharing from the prospective of energy consumption of the RAN equipment to support the same number of subscribers and/or gigabytes.

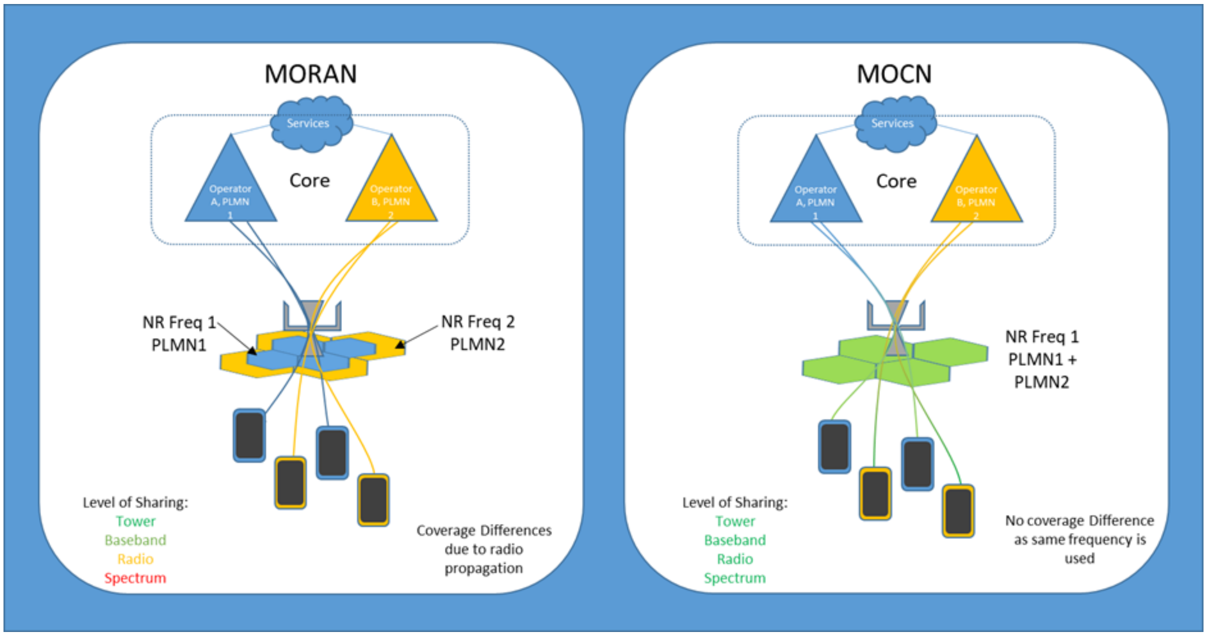
### 4.3.2 Specifications and Enablers

This section discusses two Radio Access Network (RAN) sharing concepts: Multi-Operator RAN (MORAN) and Multi-Operator Core Network (MOCN). The primary difference is that MOCN supports the sharing of spectrum assets, unlike MORAN which cannot share spectrum and thus often doesn't share radios due to different frequency bands. While MORAN allows some sharing of baseband resources, MOCN requires more coordination between operators as fewer network elements can operate independently

#### 4.3.2.1 MORAN and MOCN

From a technology standpoint there are two RAN sharing concepts that are considered available today, they are: Multi-Operator RAN (MORAN) and MOCN. The following diagram shows a simplistic overview of RAN sharing with MORAN and MOCN and their differences.

Figure 13: Illustration of MORAN and MOCN approaches, [63]source




The key difference between the two concepts is that MOCN has support for the sharing of spectrum assets. As the MORAN approach cannot share spectrum, the radios are often not shared due to the different frequency bands, instead baseband resources can be shared with some limitations (typically using a static separation rather than a dynamic one). The drawback of MOCN is that it requires more coordination between operators because fewer of the elements can function independently.

There is a third RAN sharing option called Gateway Core Network (GWCN) that can be considered an extension of MOCN where some of the Core network elements are also shared. While MORAN is not covered by any standard, MOCN is covered under 3GPP standards (3GPP TS 23.251, 3GPP TS 23.501, 3GPP TR 22.951 and 3GPP TS 25.331).

In the early 2000's 3GPP released the first specifications for MOCN in Release 6. Since then, there have been some key developments in the 3GPP standards. Due to the nature of "sharing" some important items that were considered related to the operating of the shared network such as, configuration, fault and performance management as well accounting and security.

The next diagram shows some of the developments for MOCN RAN sharing in 3GPP Specifications.

Figure 14: Source: GSMA – 5G Network Co-Construction and Sharing Guide

#### 4.3.2.2 Spectrum

Most radios and antenna products available on the market support one or a limited number of frequency bands simultaneously. Therefore, to reduce the RAN equipment, the used spectrum needs to be shared (such as can be done with the MOCN approach described earlier). This sharing may be in terms of using the same unlicensed frequency band, using licensed channels in the same frequency bands that are supported on the radio equipment, or using frequency sharing agreements.

Due to differences in propagation characteristics and bandwidth available of the different spectrum bands it is near impossible to find an optimal set of cell sites that works for radio network design of different operators unless the spectrum holdings of each are shared. Networks that have smaller bandwidth need to densify to support the same number of users and networks that have higher frequency spectrum need to more sites to cover the same geographical area. This reduces the gains in CAPEX, OPEX and energy reduction in networks using MORAN. The two aforementioned factors are also applicable to indoor and DAS systems however differences in radio propagation are of less concern.

The CBRS band has become the focus of many network sharing strategies due to:

- The PAL and GAA license model used whereby both licensed, and unlicensed – or lightly licensed – use is possible, and that PAL may be sub-leased.
- Both PAL and GAA channels offer similar propagation characteristics as well as 150MHz of spectrum providing enough capacity for multiple operators.
- Large ecosystem of products – infrastructure and end-user devices - is available to large operators (MNOs and MSOs) as well as private enterprises.

#### 4.3.2.3 Regulatory, Industry Organizations and Operator partnerships

Historically the regulatory environment in many countries has created obstacles for network sharing. The rules and laws that were created in many instances to promote competition and the sharing of anything was viewed to be anti-competitive[64].

In some countries, exceptions were made primarily with the goal of serving the underserved and rural communities. A balance was stuck and to make it financially viable to rollout digital communications to these communities, operators were allowed to form partnership agreements or joint ventures with varying levels of network sharing - from tower infrastructure to some RAN equipment. However, spectrum sharing was usually not allowed[65]

Today, regulators and legislators consider the balancing the conflicting goals of promoting competition with those of eco-friendly and sustainable mobile communications infrastructure that serves all their citizens. Sometimes rules are created such that RAN sharing is only allowed in areas where the differentiation between most operators in terms of coverage is small or the shared infrastructure is managed by a neutral third party (example are TowerCos, DAS providers, or Private Network operators) or that the networks forming a sharing club do not create a de-facto monopoly.

One form of operator partnership that has been allowed especially when a new operator enters the market is national roaming. Not only does this allow the new operator to quickly provide service to subscribers over a large area but could also be used to drive down energy consumption. One study looked at a roaming framework whereby operators with overlapping coverage decide to offload their customers to another network and shutdown their own cell sites (using sleep mode/methods) during low traffic conditions. While the concept may sound counter-intuitive to the business models that operators use, the study showed roaming based RAN sharing “can significantly improve the network energy efficiency, guaranteeing at the same time the network throughput in realistic scenarios of up to four MNOs”[66].

The same concept can be used by operators that have mobile offload (or MVNO) agreements with other operators with the use of Dual-SIM Dual-Standby (more later).

Finally with the rise of Private Networks, CloudRAN and CloudCore that are operated and managed by smaller enterprises (vs traditional MNO or MSO), new forms of RAN sharing agreements are to be expected. These agreements may result in enterprises deploying their Private Networks and allowing public operators to share their network which reduces the duplication of coverage and reduces energy consumption. This has advantages over traditional DAS as no additional equipment needs to be deployed by the public operators to make use of the network thereby eliminating many of the cons of DAS systems mentioned in section 5.2.1.

#### 4.3.2.4 Other Enablers

Many of techniques proposed in this whitepaper that can help operators reach their sustainability goals can also be used as enablers for multi-operator / shared networks. This section covers some other enablers for RAN sharing that should be considered by our readers when building their sustainability strategies.

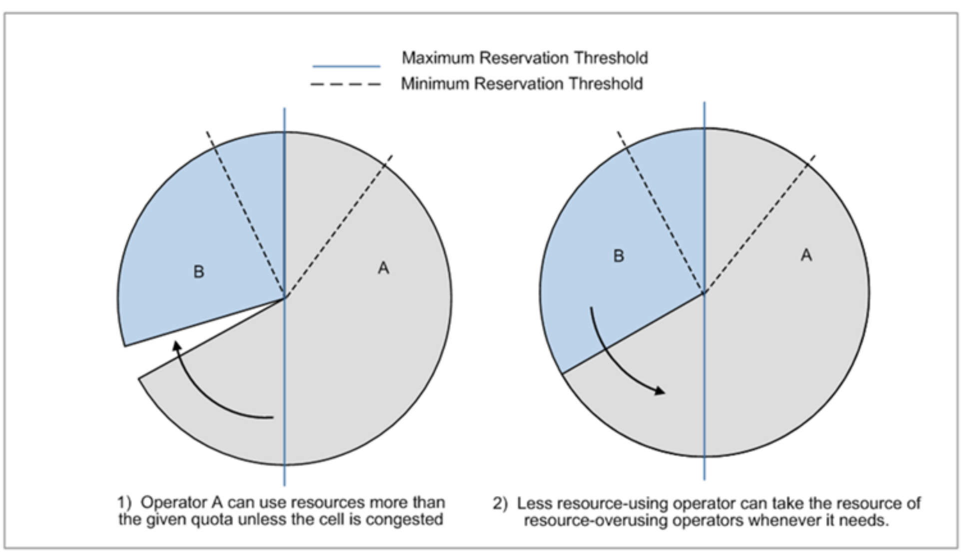
Virtualized RAN (vRAN) solutions - and variants such as OpenRAN - may be able to reduce energy consumption using two key concepts:

- **Elastic Scaling** – This allows the operator to use just the right number of resources to support the network demands. When the processing demands are low, the operator can quickly and efficiently place VNFs (such as vDU and vCU) into deep sleep states.
- **Resource Pooling** – While this is more of a benefit of CRAN (centralized RAN), vRAN enables this far more effectively[67]. For example, if traffic migrates during the day from residential areas to central business areas and back, then some of the same vRAN resources can be used to support the traffic instead of having dedicated resources for each of the two areas.

For further elaboration of virtualization solutions, please see Section 4.4. In the context of network sharing, notably, the above vRAN concepts and the benefits of vRAN can be extended to a RAN sharing environment with multiple operators. For instance, if two operators have different traffic trends (for example, one is for Machine-to-Machine Type Communications with 24-hour continuous low level traffic versus another operator with enhanced mobile broadband traffic) then the resources can be scaled accordingly. Resource pooling can also be used to share the resources efficiently across multiple operators and potentially locate the resources where alternative energy sources are abundant and where passive or more energy-efficient cooling is available (for example in colder regions in the country).

Resource allocation is important for RAN sharing and developments such as network slicing and flexible resource allocation models have been developed to provide a framework that operators can use to share the RAN equipment efficiently. An example of a resource allocation based on proportional fair principles is shown below:

**Figure 15: Examples of resource allocations between operators A and B using RAN sharing[68]**

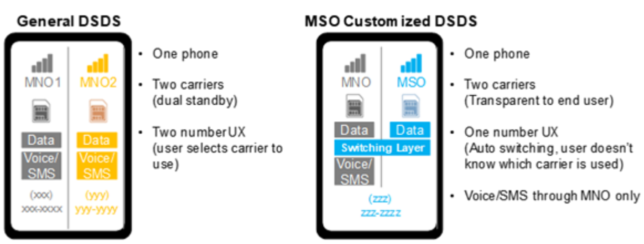


For many years, MNOs have made extensive use of ML and AI capabilities, albeit under different names such as Self-Optimizing-Networks (SON), Plug-and-Play and Self Configuration, and Expert Tools that can correlate Alarms, Configuration Changes, and trends in performance metrics to predict outages, diagnose problems and perform self-healing actions. A shared network has more dependencies and interactions to consider which may be beyond what humans are capable of tracking, therefore the use of AI/ML as described in Section 3.5 is of even more importance and must be developed to support shared networks.

Furthermore, Dual-SIM Dual-Standby (DSDS) functionality has been around for a while. Previously, it was used merely as a way for the end consumer to manually switch between two networks to take advantage of better tariffs. Today, operators use this functionality to automatically switch their subscribers to a partner network for reasons such as providing voice services when they do not (want to) support it, providing “roaming” coverage, or offloading traffic. This usually happens without the end consumer knowing that it is happening.

The next diagram shows how DSDS functionality is used by MSO companies like Charter[69] and Comcast[70] to use wholesale MVNO agreements for blanket coverage and use their own base stations in high-traffic areas.

**Figure 16: General DSDS functionality (left) and DSDS functionality used by MSO companies (right), source[71]**

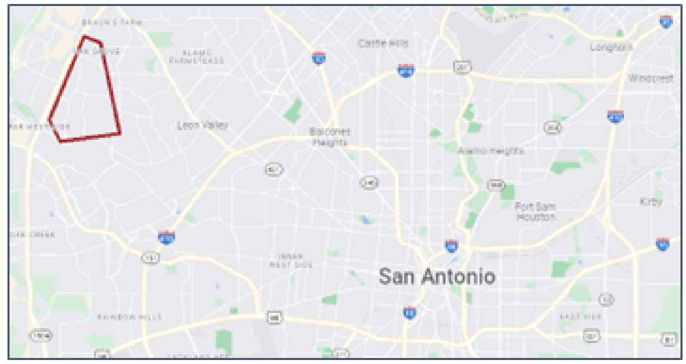



This allows MSOs and Enterprises to deploy resources only where it is cost-effective to do so. In the future, cost calculations could consider the energy consumption versus the offload costs and enable sleep features when it is appropriate (for example after business hours).

### 4.3.3 Case Studies

In the following, we show a small cell case study about sharing the RRU. Although RRU sharing is not currently adopted, we want to prove its potential sustainability benefits. A 12 square-kilometer polygon was identified in the Northwest Crossing suburb of San Antonio, TX for a small cell design.

**Figure 17: Shared radio small cell case study polygon**



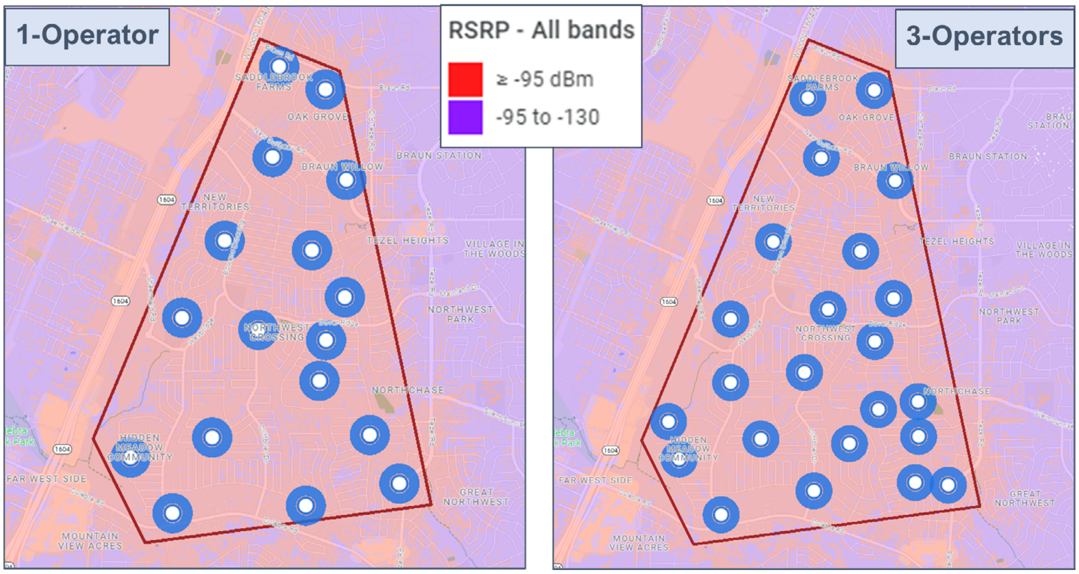

The small cell network was designed using the following parameters.

**Table 1: Radio parameters**

| | |
|---|---|
| Frequency Band | PCS |
| Channel Bandwidth (MHz) | 20 |
| Radio Antenna Ports | 4 |
| Output Power/Port (W) | 40 |
| Antenna Type | Omni-directional |
| Antenna Gain (dBi) | 12.7 |
| Antenna Height (m) | 12 |
| RSRP Coverage Target | -95 |
| Target Coverage Area (%) | 90 |

The network was first designed in the traditional way where the RRU was dedicated to a single operator. The network was then redesigned to share an RRU between three operators. The main factor impacting the design was the need to share the radio output power between all three operators, resulting in additional small cell nodes to cover the same geographical area.

**Figure 18: Shared radio small cell case study designs**




The following statistics were derived from this analysis:

| | Dedicated Radio | Shared Radio |
|---|---|---|
| Node Count | 17 | 23 |
| Average Power Consumption/Radio (W) | 299* | 383** |
| Average Power Consumption/Node (W) | 897 | 383 |
| Total Network Power Consumption (W) | 15249 | 8809 |
| Total Annual Network Energy Consumption (MWh) | 133.6 | 77.2 |

* Based on radio equipment manufacturer's specified LTE FDD ETSI Medium Traffic Model Power Consumption

** Based on radio equipment manufacturer's specified LTE FDD ETSI Busy Hour Traffic Model Consumption

The results of this case study show, based on the defined parameters, that a shared radio configuration in an outdoor small cell deployment can save upwards of 42% in energy consumption even when 35% more node locations are required to cover the same amount of geography. One main assumption is the average power consumption by the radios. If a radio is only being used by a single operator, the average power consumed will be less than if three operators are sharing that same radio, so a Medium Traffic Model was used for the single-operator case and a Busy Hour Traffic Model was used for the three-operator case (ETSI TS 102 706-2 V1.5.1). If the same exercise is completed for frequency bands higher than PCS (1.96 GHz), the energy consumption savings will go down due to the decreased propagation characteristics of higher frequencies and ultimately an increase in the delta of nodes required. For the AWS band (2.15 GHz), the node count was 18 for one operator and 28 for three operators, resulting in a 34% energy savings. For C-band (3.84 GHz), the node count was 38 for one operator and 67 for three operators, resulting in a 16% energy savings.

This case study focused specifically on energy consumption improvements, but the cost of shared radio deployments cannot be overlooked as a barrier to achieve these energy-saving benefits. For example, in the PCS case study, there were six additional nodes required when the radios were shared. The costs to build a small cell node can vary depending on the specific location, and each node requires fiber connectivity, which also varies in cost from one location to the next. If we assume a relatively inexpensive small cell construction cost of $50,000 per node, consisting of $20,000 for the node itself and $30,000 for the short fiber run from the fiber backbone to the node, it will cost $300,000 more ($100,000 per operator if shared equally) to build a shared radio network for this 12 square-kilometer polygon. Based on the potential energy savings, and assuming an average commercial electricity rate of $0.12/kWh across the US as reported by the U.S. Energy Information Administration (EIA), each operator will save about $2,300 per year on electricity costs. Therefore, it will take just over 44 years for each operator to recover the cost to build the extra node locations, which obviously indicates that the motivation to go to a shared radio small cell model needs to be an ESG story rather than a financial story.

There are also some other design and performance considerations that can be implemented to reduce the number of additional small cell nodes required, such as relaxing the coverage requirement, increasing the antenna gain, boosting the reference signal, or leaning on features such as Coordinated Multi-point (CoMP). Finally, the potential to use existing vertical infrastructure, due to the decreased size and weight of the radio equipment (one or two radios versus three or six), and innovations in fiber deployment methods could turn the financial model in favor of the shared radio deployment.

## 4.4 Virtualization, Optimized Workload Instantiation and Open RAN

In the last decade, MNOs started adopting network virtualization a new technology paradigm where dedicated physical devices are replaced with generic hardware platforms running equivalent functions implemented in software, packaged and deployed using orchestration frameworks. This shift towards software-based networks has evolved and the industry has started to adopt cloud-native architecture based on micro-services. The Network Function Virtualization (NFV) deployments are leveraging, in addition to Virtual Machine (VM), container-based frameworks for packaging and orchestration such as Docker and Kubernetes.

While providing other operational benefits such as rapid deployment, flexibility and scalability, NFV also offers opportunities to MNOs to reduce energy consumption. The ability to scale the networks based on just-in-time needs allows for a more judicious and dynamic instantiation of network functions therefore increasing the energy efficiency, while reducing OPEX as well. Using orchestration frameworks enabled with analytics and prediction models, operators can shut down instances of Software-based Network Functions during periods of low usage and consequentially reducing the power usage.

Combined with Software Defined Networking (SDN), another networking technology that uses software-based controllers and APIs to route traffic on the network, NFV brings efficiency in the network management.

For most operators, virtualizing the network is also an opportunity to improve overall asset utilization and network energy efficiency by systematically decommissioning and removing obsolete network hardware.

A contemporary paper on telecommunication networks would be remiss not to touch on Open Radio Access Networks (Open RAN) and how it may play into any future strategies or goals. When it comes to mobile communication network sustainability, Open RAN promises to play a prominent role. In fact, improved efficiency is one of the main goals for Open RAN vendors as they look to differentiate themselves from the traditional, purpose-built RAN products. Deutsche Telekom, Orange, Telefónica, TIM, and Vodafone collaborated to publish an Open RAN Technical Priorities document to ensure energy efficiency is a priority in Open RAN development.

As shown in Section 2, the RAN is the main contributor to energy consumption in the mobile communication network, having a share anywhere between 70-85% of the total energy consumption in the network. The RAN architecture typically consists of a baseband unit (BBU), or a combination of a virtualized Central Unit (vCU) and virtualized Distributed Unit (vDU), and a remote radio unit (RRU) or generally the radio unit (RU). The RRU/RU is by far the main contributor to the overall RAN power consumption. The RRU/RU is responsible for transmitting the wireless channels over large areas (measured in hundred meters or kilometers) and through walls into homes and offices.

Typical macro RRU output power is in the 160 W range per frequency band (40 W per antenna port). Due to the need for high linearity (a very clean signal to minimize any interference in adjacent channels or frequency bands) the typical efficiency of an RRU is 24-28% when operating at maximum power. Even the more advanced massive MIMO RUs, designed to achieve superior spectral density, can only attain similar, and sometimes worse, power efficiency values.

One of the main premises behind Open RAN is open interfaces between network components, which should enable increased vendor competition to design, manufacture, and produce these individual RAN components to the wireless operator customers. Increased competition often leads to advanced innovation, which can result in incremental improvements in PA efficiency through improved designs or advanced component selection. Additionally, specialized software companies can optimize the Service Management and Orchestration (SMO) layer of an Open RAN solution. Using AI and ML, applications within the RAN Intelligent Controller (RIC) can automatically adjust RRU outputs based on traffic patterns and usage demand, optimizing efficiency. For example, at the 2022 Global Spring plugfest of the O-RAN Alliance, Vodafone, Intel, Radisys, Wind River, and Keysight teamed up to quantify the reduction in power consumption of a multi-vendor, cloud-based, and fully virtualized O-RAN system. Their testing claimed to achieve between 9-12% power consumption reduction for high-traffic and low traffic scenarios, respectively.

Although less power hungry than the RRU, the CU and DU can benefit from new rApps in the RIC that optimize power consumption through enablement of advanced sleep mode functions. Add that on top of individual component level efficiency improvement, and it can all add up to significant reductions in carbon emissions. For example, Ericsson has developed an rApp that reduces the daily radio network energy consumption by up to 25 percent without impacting user experience by autonomously determining which radio power-saving features per radio unit should be activated or deactivated every 15 minutes across the whole network on a radio unit-level of granularity.

# 5. Applications and Services Energy Efficiency Techniques

Media delivery is an important use case for mobile networks. As new mid-band TDD spectrum is deployed for 5G, users are finding they can stream videos to their devices for entertainment and educational value and they can join video conferencing from the most unsuspected locations. There are both user-side and network-side impacts to energy consumption associated to streaming video. Streaming video requires advanced network-side compression and user-side decompression.

Streaming video is almost always delivered as HTTP adaptive streaming or HAS. In this approach, the user device uses HTTP to request “chunks” of video content to populate a playout buffer on the device. These chunks are then decoded by the application processor for rendering on the device screen. Chunks carry playout content for a 30 frames-per-second display rate however, the encoding of the chunks can vary. For example, an encoding at a higher number of pixels per display size (typically, the horizontal line in the display) will consume more throughput and associated transport capacity over-the-air interface. By monitoring the fill in the playout buffer, the mobile device can request chunks to be delivered by HTTP and can also request a specific playout resolution. The main benefit of HAS is the adaptive nature it demonstrates. In the face of congestion, the UE algorithm will request smaller chunks resulting in lower resource consumption. If there is less congestion, then bigger chunks can be requested. Unfortunately, this UE-side algorithm is greedy and would request larger chunks even if unnecessary or inappropriate to the video display size.

Operators leverage the HAS mechanism to optimize delivery to the display in the playout device. This technique goes by the name of “traffic shaping”, and it is ordinarily implemented to save capacity via the over-the-air interface. Traffic shaping at the mobile network identifies video streaming flows from packet heuristics, and then rate limits them so that the user device algorithm behaves as if under congestion conditions. The degree of bitstream capping is set to the size of the display device which is inferred at the start of the HTTP negotiation. Generally, traffic shaping does not impact user QoE and can be implemented even when traffic is per-session encrypted. When traffic shaping is not implemented, congestion can ensue very quickly even under low traffic conditions.

Traffic shaping also saves energy. On the network side, streaming servers are less busy when flows are shaped and so can serve more subscribers. On the user side, battery life is extended because decompression algorithms are less taxing. This assumes decode processing is done on a general-purpose CPU core in the mobile application SoC. Operators benefit doubly when shaping video because: (a) they create more capacity in their networks and (2) they improve user QoE by prolonging battery life. For third-party streaming providers, shaping also provides a benefit in that their resources can efficiently support a larger number of users at a lower energy cost.

Media delivery optimization over mobile networks is another mechanism that can help reduce energy usage from the content provider all the way to the mobile device. As an example, AT&T Video Optimizer is a free, open-source tool that helps app developers improve the performance of their apps. The tool also helps developers optimize mobile apps so that they use the mobile network efficiently. Not only does this make for a better user experience, but it also helps app providers save money on data center equipment that they don’t have to use because they’re serving content more efficiently.

Carbon Trust and BSR® collaborated with AT&T in the development of a methodology to measure the carbon benefits of AT&T's Video Optimizer technology. Because the benefits from AT&T Video Optimizer have global scale, even small adjustments to app code can result in an environmental benefit. When an app is optimized, the network energy efficiency benefits extend to wherever in the world the app is used. And smaller file size extends device battery life and reduces battery charging needs, reducing energy usage further. Together, these benefits add up to more than 42,000 kWh in electricity savings a year across the globe, which is equivalent to more than 25,000 metric tons of $CO_2$ each year.

Greening of Streaming is a relatively new initiative focused on end-to-end energy efficiency in the technical supply chain underpinning streaming services. They are working on defining the LESS Accord (Low Energy Sustainable Streaming), a set of best practices for how compression technologies should be employed across streaming video workflows to maximize their energy efficiency while maintaining a default good QoE for viewers.

# 6. Site Solutions Based on Renewable Energy

In the U.S. alone, there were 142,100 cellular towers in operation at the end of 2022 according to a Wireless Infrastructure Association (WIA) paper published in Q1 2023. Of course, the specific environments where each cell tower is deployed can vary significantly between dense urban areas (a), open rural spaces (b), and everything in-between.

**Figure 19: Examples of cell tower deployments: (a) dense urban areas and (b) open rural spaces**

a)  b) 

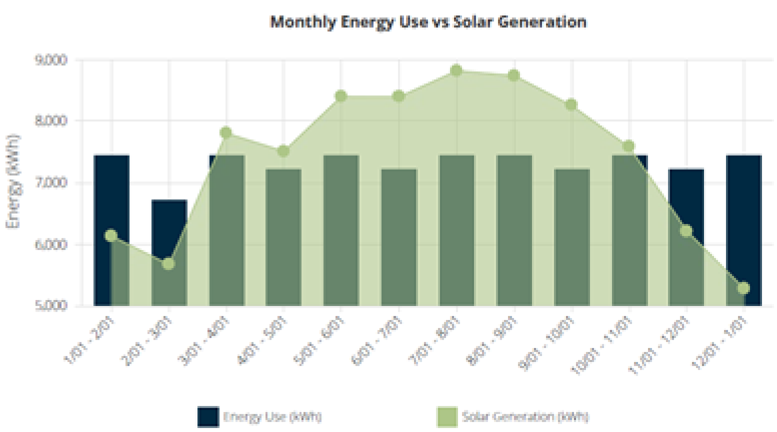
Over the years, the equipment deployed on cell sites has evolved. As wireless capacity has grown rapidly, more and more frequency bands have been dedicated and sold by the Federal Communications Commission (FCC) to commercial wireless operators to keep up with the demand. Radio efficiency has improved over the years, but overall power consumption per radio has continued to go up due to increased transmit power levels or more antenna output ports. The power consumption per site varies based on the number of frequency bands supported, the types of radios deployed, and the vintage of equipment. Average site consumption is around 10kW for the top MNOs in the U.S., which equates to 87,600 kWh/year. Many cell towers are shared and support multiple MNOs as well as smaller wireless customers, such as IoT network providers or public safety network providers, so the average power consumption for a cell site can be upwards of 50kW or 438,000 kWh/year. To put this in context, the Energy Information Administration (EIA) reported in 2021 that the average annual electricity consumption for a U.S. residential customer was 10,632 kWh. So, the average shared cell tower consumes enough electricity to support over 40 residential homes.

Of the 142,100 cell sites in the U.S., it is safe to assume as a conservative estimate, that at least 5% are located on real estate plots over 20,000 square feet in size, which equates to over 7,000 cell sites nationwide. If it is also assumed that there are 1.5 wireless operators with equipment deployed on those cell sites on average, that would add up to a composite electricity consumption equal to over 86,500 residential homes.

Deploying solar panels at cell sites with excess real estate could significantly reduce carbon emissions. From a financial perspective, the price of electricity from solar declined by 89% from 2009 to 2019. Add on top of that the recent federal or state tax incentives made available when deploying renewable energy, and there is now a great opportunity to not only move down the path towards Net Zero emissions, but to also reduce operational expenditures. One deployment model would be to design and install enough solar capacity so that excess electricity can be sent back to the grid during peak generation hours as credits against grid electricity usage during non-daylight hours. This model is sometimes referred to as grid-as-a-battery. The example graph shown below is for a cell site in Southern California with an average power consumption of 10kW. The amount of space required to generate enough electricity to 100% offset the 87,600-kWh consumed is less than 4,000 sq ft.

Alternatively, a battery energy storage system (BESS) can be provisioned along with solar panels in the case where the grid does not provide energy credits or simply cannot support bi-directional electricity meter applications. The batteries will charge up during the day when there is excess electricity generated and discharge to the load overnight when the solar array is not generating electricity. The downside of provisioning batteries is that it can more than double the total system cost, effectively doubling the levelized cost of energy (LCOE).

**Figure 20: Monthly energy used by the network vs solar-generated energy**
**Source: Motive Energy Telecommunications Group, Inc.**




Although the cost to deploy solar has never been cheaper, energy from the grid in many markets can also be relatively inexpensive. This can make the business case challenging if the goal is to deploy renewable energy at scale across the country. The solution may need to be optimized for size, cost, and time of energy usage. If the electricity rates vary throughout the day, the solar system can be designed to only offset the electricity consumed at peak rate hours. The resulting renewable energy solution will be both smaller and lower cost, which can result in a larger number of deployments.

**Figure 21: Example of a site with solar generation of energy, Source: Google Maps**

Wind energy is another path to reduce carbon emissions. There are two basic types of wind turbines: Horizontal-axis wind turbines (HAWT) and Vertical-axis wind turbines (VAWT). HAWTs are more efficient than VAWTs because they can generate energy through the full rotation of the blades. VAWTs, on the other hand, operate better in slower or more turbulent wind environments and can be placed closer together, so they may be preferred in more urban or suburban environments.

A cell site can be challenging for a HAWT due to the need for lots of space and separation from other vertical structures to maximize energy production and efficiency. That said, Germany-based MOWEA GmbH has developed mini modular HAWTs that can be deployed on the side of cell towers. Vantage Towers has agreed to deploy 752 of these micro turbines on 52 of its cell towers. They believe these wind turbines will generate enough renewable energy to power 100% of the site's electricity needs.

**Figure 22: Example of a site with wind turbines, Source: MOWEA**

# 7. 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.

To enable these businesses to reach their goals, climate centered partnerships by wireless carriers and vendors are being developed to tap into the potential that connectivity brings to monitor, track and optimize operations for a variety of vertical industries These initiatives aim to accelerate climate progress and highlight how companies can collaborate to reduce global emissions through connectivity-based solutions.

Smart building technology is playing a major role in delivering sustainable outcomes and connectivity plays a key enabler. Power over Ethernet, for example, in its 90W variant called Universal Power over Ethernet Plus ("UPOE+") is finding a role delivering DC power over copper Ethernet cabling to endpoint devices such as automatic shades, LED-based lighting fixtures, video cameras and other sensors, and user devices. UPOE+ is also powering Wi-Fi access points and, 5G small cells. Apart from the UPOE+ connectivity, Wi-Fi and indoor 5G can be used to support connectivity to a broad array of sensor devices. A smart building controller leverages the connectivity to build a broad variety of "if x then do y" building policy scenarios based on using data collected from this inbuilding "network-of-things" in an intelligent way in accordance with desired outcomes associated to conserving energy, improving health and safety, and reducing staffing costs. For smart buildings, the connectivity strategy will certainly require a complement of wired and wireless technologies including Ethernet/UPOE+, 5G, and Wi-Fi.

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.

Enterprises can create immediate electricity and cost savings without upfront capital investment. Using Internet of Things connectivity, companies can accurately measure and model the energy savings that enterprises can realize through implementation of energy-efficient technologies. That information helps them generate immediate electricity cost savings for their users, while also allowing them to pay for the installation of the technology over time.

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.

# Conclusion

MNOs and network vendors have set aggressive sustainability targets for the next decade along with other industries aiming at reducing their carbon footprint. While there are multiple techniques they employ 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.

This paper introduced existing technical capabilities, deployment strategies and other operational techniques that can be used by MNOs to increase 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.

# Appendix

## Acronyms

AI: Artificial intelligence

APN: Access Point Name

AWS: Advanced Wireless Service

BBU: Baseband Unit

BEREC: Body of European Regulators for Electronic Communications

BESS: Battery energy storage system

BWP: Bandwidth part

CAPEX: Capital Expenditures

CBRS: Citizen's Broadband Radio Service

CCI: Connected Climate Initiative

CoMP: Coordinated Multi-point

CPRI: Common Public Radio Interface

CPU: Central Processing Unit

CRAN: Centralized Radio Access Network

CSP: Communication service provider

CU: Centralized Unit

DAS: Distributed Antenna System

DPD: Digital Pre-Distortion

DRAN: Distributed Radio Access Network

DSDS: Dual-SIM Dual-Standby

DTX: Discontinuous transmission

DU: Distributed Unit

EaaS: Efficiency-as-a-Service

EBMS: Energy and Building Management Solution

EIA: Energy Information Administration

EMBB: Enhanced Mobile Broadband

ESG: Environmental Social Governance

FCC: Federal Communications Commission

GAA: General Authorized Access

GDP: Gross Domestic Product

GHG: Greenhouse gas

GSMA: Global Systems for Mobile Communications Association

GWCN: Gateway Core Network

HAS: HTTP Adaptive Streaming

HAWT: Horizontal-axis wind turbines

HVAC: Heating, Ventilation, and Air Conditioning

IBW: Inbuilding Wireless

ICT: Information and Communications Technology

IDF: Intermediate distribution frame

IMS: IP Multimedia

IoT: Internet of Things

IP: Internet Protocol

IPCC: Intergovernmental Panel on Climate Change

ITU: International Telecommunication Union

LCOE: Levelized cost of energy

LESS: Low Energy Sustainable Streaming

LTE: Long Term Evolution

MDF: Main distribution frame

MIMO: Multiple-input multiple-output

ML: Machine learning

MNO: Mobile network operators

MOCN: Multi-Operator Core Network

MORAN: Multi-Operator Radio Access Network

MRSS: Multi-RAT spectrum sharing

MSO: Mobile Service Operator

MVNO: Mobile Virtual Network Operator

NF: Network Function

NFV: Network Function Virtualization

NGMN: Next Generation Mobile Networks

NPN: Non-Public Network

NR: New Radio

NRA: National regulator authorities

OAM: Operation, Administration, and Maintenance

OFDM: Orthogonal frequency division multiplexing

OpenRAN: Open Radio Access Network

OPEX: Operational expenditures

PA: Power amplifiers

PAL: Priority Access License

PAPR: Peak to average power ratio

PCS: Personal Communication Service

QoE: Quality of Experience

RAN: Radio access network

RF: Radio Frequency

RH: Radio Heads

RIC: RAN Intelligent Controller

RRU: Remote radio unit

RU: Remote Units

SC: Small cells

SDN: Software Defined Networking

SIB: System Information Block

SMO: Service Management and Orchestration

SoC: System-on-a-chip

SON: Self-Optimizing-Networks

SSB: Synchronization Signal Block

TDD: Time Division Duplex

UE: User Equipment

UL: Uplink

UPF: User Plane Function

UPOE: Universal Power over Ethernet

U.S.: United States

VAWT: Vertical-axis wind turbines

VLAN: Virtual Local Area Network

VM: Virtual Machine

VNF: Virtual Network Function

VoIP: Voice over Internet Protocol

VoNR: Voice over New Radio

vRAN: Virtualized RAN

WIA: Wireless Infrastructure Association

# Acknowledgments

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

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