Network Energy Efficiency Phase 3A

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EFFECTIVE ENERGY SAVING STRATEGIES AND BEST PRACTICES FOR MNOs

by NGMN Alliance

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EXECUTIVE SUMMARY

In recent years, Mobile Network Operators (MNOs) have faced a more complex business environment. Tightening energy markets as well as spikes in natural gas prices have contributed to a challenging energy landscape. The significant increase in MNOs' operational costs impacted efforts to deliver on transformational connectivity goals and meet investment targets. Fortunately, MNOs are responding collectively to mitigate this crisis by: (1) reducing energy consumption by implementing efficiency measures, and (2) by ensuring stability of energy supply.

To increase energy efficiency, MNOs implemented a variety of methods, and amongst these, the most effective ones are highlighted in this publication. Specifically, MNOs have suggested to shut down legacy networks, re-farming spectrum for more energy efficient radio access technologies (RATs). They have also stressed the need to accelerate the modernisation of Radio Access Network (RAN) equipment to integrate more energy efficient hardware. In addition, power saving features should be implemented, such as switching off capacity carrier frequencies during periods of low traffic. Importantly, the state of extreme deep dormancy could be activated as a means to further optimise energy consumption at the Base Station (BS). Other methods have been explored by some MNOs in an effort to reduce energy consumption. These included simplified architectures at a network site to reduce the need for active cooling, using more advanced monitoring and control systems and looking at liquid cooling. To ensure stability of energy supply, MNOs are working to accelerate the transition to renewable sources of energy for network sites combined with back-up battery storage. MNOs also seek to optimise network energy flexibility.

Ultimately, the collective MNO response to this challenging energy landscape yielded a range of methods that were regarded as "best practice" that could be relevant for future solutions, should the energy crisis persist. This involved shutting down 2G and 3G where possible, shifting to more energy efficient RAN equipment especially in 4G and 5G deployments. Moreover, shifting from legacy airconditioning units towards more energy efficient cooling solutions could be an effective way to optimise energy consumption.

NGMN will argue for the above recommendations to mitigate the energy challenges experienced by MNOs. Future work that builds on this publication will also look at novel technologies that can support such efforts to make mobile networks greener by improving network energy efficiency. This could include looking at Artificial Intelligence (AI) for more intelligent energy management. It involves also looking at new opportunities for embedding software in the mobile networks.

CONTENTS

01 SCOPE AND INTRODUCTION

Energy efficiency, along with strategies towards significant reduction in energy consumption, coupled with minimisation and elimination of energy waste, has become an essential requirement. This responds to environmental as well as economic sustainability, particularly in the presence of the ongoing energy challenges. These challenges include the significant increase in processing of data with new and expanded network capabilities, despite the more efficient 5G technology.

The purpose of this publication is to tackle the recent energy price spike challenges confronting the telecoms industry, which are exacerbating the need to improve network energy efficiency. This is the first piece of the NGMN Alliance (NGMN) work that demonstrates a collective MNO response to the challenging energy landscape through reduction in energy consumption and efforts to safeguard energy stability without negatively impacting the network performance. It follows previous NGMN publications on the topic of Network Energy Efficiency [1] [2].

Section 2 contextualises the energy price volatility challenges that were acutely felt by the telecoms industry, especially for MNOs. Section 3 then introduces the MNO response to this challenging climate in two ways: firstly, in Section 4, by outlining the methods used to reduce network energy consumption, and secondly, in Section 5, by presenting solutions to ensure energy stability so as not to undermine quality of service. The United Nations energy related goal ensuring access to affordable, reliable, sustainable and modern energy for all requires increasing the renewable energy sources in mobile network operators' total final energy consumption and decreasing the energy consumption of the equipment. Finally, Section 6 handles the key learnings from this analysis, highlighting the best practice undertaken by MNOs.

02 CHALLENGES FOR THE TELCO SECTOR

Energy markets began to tighten in 2021 due to a variety of factors:

1. the extraordinarily rapid economic rebound following the COVID-19 pandemic which increased the demand for energy,
2. a long, cold winter in the Northern Hemisphere which increased energy demand across the whole world,
3. a weaker-than-expected increase in energy supply.

Natural gas prices have seen the biggest increase, hitting historical maximums.[1] The significance of the energy situation has further grown, especially in 2022, mainly due to a reduction in supply, the disruption of energy trade flows, and competition for gas supply security. These prices reached their maximum in July and August 2022.

Against this challenging backdrop of sustained energy price rises, it became a priority in the telecoms sector to attempt to reduce energy costs as much as possible by securing and stabilising whatever energy was available. However, another crucial component of the telecoms industry's energy transition involves altering energy consumption patterns on the network side by increasing network energy efficiency as well as transitioning towards renewable energy sources to reduce greenhouse gas (GHG) emissions aligned with the goal to mitigate climate change while satisfying the need for expanded network capabilities.

Given the unprecedented and acute nature of price rises in 2022, the telecommunications industry has been faced with significantly increased operating costs; however, attempts to secure energy supply to combat these rises in the short term should not defer other important energy transition actions. In this context, energy efficiency, particularly in the mobile networks will be an even more important part of the energy transition and essential to get right, helping to reduce energy costs and GHG emissions across the globe.

In addition, if national power grids were temporarily unable to provide electricity, MNOs may face the threat of network outages which could lead to loss of service within hours, or even instantaneously for sites that lack back-up electricity. These two risk factors combined could undermine the telecommunication industry's ambitious societal targets to deliver for citizens, governments, and businesses.

1 Source: IEA - What is behind soaring energy prices and what happens next?

03 MNO RESPONSE TO THE CRISIS

MNOs took steps to manage the energy crisis. Broadly, this falls into two categories: (1) reducing energy consumption, and (2) ensuring energy stability to maintain service continuity. This includes developing solutions to support the transition to greener and more resilient networks and to optimise network energy efficiency, i.e., the number of delivered useful bits per unit of consumed energy. To satisfy the request for novel mobile services and stringent performance requirements, MNOs have deployed new sites. Although this contributes to increase the energy consumption, many MNOs kept the overall net energy consumption broadly flat by gradually shifting to more energy efficient technologies. These include further deployment of new radio access technologies (RATs), where 4G and 5G are at least five times more energy efficient than 3G when carrying the same amount of traffic and the application of 5G Massive Multiple Input Multiple Output (M-MIMO) which is at least three times more energy efficient than 4G M-MIMO [2]. Consolidation of fixed access and the core/data centre network infrastructure improves energy efficiency. Another mechanism to optimise energy consumption is via dynamic use of low power modes.

To assist in the delivery of the above energy efficiency optimisation aims, MNOs are strongly reducing the energy consumption of the RAN, which accounts for almost three-quarters of total network energy consumption by

- shutting down 2G and 3G networks, wherever possible,[2] and refarming 2G and 3G spectrum for more energy efficient RATs (e.g., LTE and NR),[3]
- accelerating modernisation of RAN equipment to benefit from next generation energy efficient solutions,
- implementing power saving features to switch off capacity layers during periods of low traffic demand without negatively affecting the user performance.

The following subsections describe in more detail methods being used by MNOs to manage the energy challenges.

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2 According to Analysis Mason, MNOs that run 2G, 3G, 4G and 5G with separate BSs could potentially reduce their energy consumption by up to 24.4% at each macro site by switching off 3G [8]

3 https://www.telekom.com/en/media/media-information/archive/bye-bye-3g-now-lte-is-coming-for-everyone-608220

04 REDUCING ENERGY CONSUMPTION

This section describes the methods used by MNOs to reduce or optimise energy consumption as part of efforts to deal with a challenging energy landscape. The main methods used, each of which is described in turn, were: improving site energy efficiency, deploying monitoring and control systems to check energy consumption and network performance parameters, improving power and cooling efficiency, and optimising energy consumption at the base station through novel sleeping features.

4.1 IMPROVING THE SITE ENERGY EFFICIENCY THROUGH MODULAR SITE ARCHITECTURES

As discussed in [2], the Radio Access Network (RAN) accounts for around three-quarters of all mobile network electricity consumption with the Base Station (BS) typically resulting for more than half of the electricity consumption of a typical cell site. In addition to the BS, the energy consumption of the site support equipment is significant. In traditional sites, based on the architecture shown below in Figure 1, the site support equipment power consumption, mainly driven by the air-conditioned equipment room, can be as great as 40% of the total site energy consumption. All power consumed at a site is the sum of BS power consumption and site support equipment power consumption, with the precise ratio being influenced by a range of environmental factors. In a cooler environment with passive cooling the air conditioning load is small, in a warmer external environment the air conditioning load would be significantly higher. Novel site design solutions can determine which sites really need air conditioning and a temperature control system, so that these are deployed only where required.

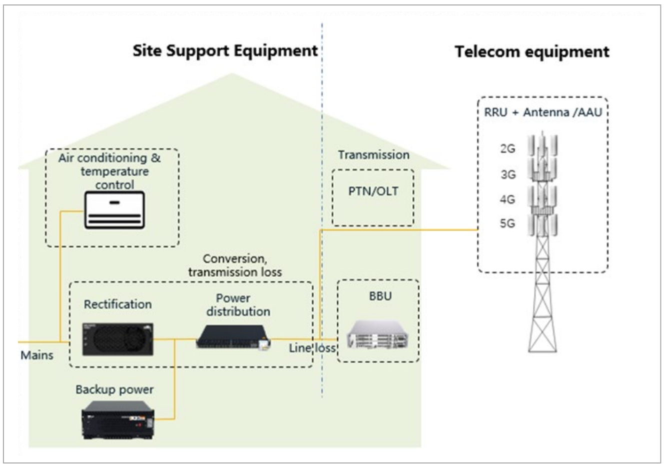


Figure 1: Traditional site with indoor site support equipment

Given that the total site energy consumption is the sum of BS and site support equipment consumption, this can be limited by reducing energy consumption of either or both of these two components. The following subsection focuses on improving site energy efficiency by reducing site support equipment energy consumption. Partly, this optimisation involves limiting the power consumption of multiple site support equipment components.

Historically, access site deployment involved placing site support equipment indoors while the telecoms equipment (e.g., BS, RRUs and antennae) were located outdoors. With modular site architectures, site support equipment could be moved from traditional indoor sites to outdoor sites as shown in Figure 2. Shifting some of this equipment outdoors together with further deployment of outdoor poles results in reduced energy consumption by outdoor cooling. This approach also reduces power loss due to the conversion for power continuity, which can be further minimised with the deployment of state-of-the-art power solutions that have high conversion efficiency.

Switching off legacy radio access technologies (RATs) has been associated with transitions to simpler architectures and with novel hardware able to run at higher temperatures, which allows the deployment of more modular components outdoors rather than indoors.

A variant of this approach involved placing network components, e.g., antennas, radio, and Baseband units (BBUs), which can support multiple technologies, in one centralised piece of equipment, without adversely affecting user experience on the live network.[4]

Figure 2: Traditional and simplified sites

It is important to highlight that achieving low-cost heat dissipation control, efficient heat management, and high reliability in a simplified site operating in different environmental conditions, hardware configurations and processing requirements, is a challenge, which requires system design methods based on accurate thermal simulation design and integrated performance verification capabilities.

Going forwards, to evaluate the energy-saving effectiveness of these simplified architectures fully, it is necessary to reach a consensus on the scope of the site energy efficiency (SEE). Should it focus on the RAN only or also include the transport network? The collection of site energy consumption data is a pre-requisite in the SEE evaluation. Potentially, this could be assisted by automation of some processes, whose energy consumption impact should be considered.[5]

4.2 MONITORING AND CONTROL SYSTEMS

To analyse and then improve the overall energy efficiency, is key to deploy monitoring systems on energy usage, traffic, and network performance. A monitoring system allows data management and analytics by collecting, processing, and storing data feeds from electricity suppliers and smart meters. Effective monitoring of energy consumption, data traffic, and configuration data feeds have paved the way to embed some degree of automation to control and optimise energy efficiency.

In this context, some MNOs have already used the following technologies leveraging the availability of energy and network data:

- **Energy saving features** to, for example, put the RAN sites in low power mode during low traffic periods. These features allow further monitoring, tracking, and assessing the impact on energy savings in the network and business Key Performance Indicators (KPIs).
- **Passive infrastructure optimisation** to monitor energy consumption metrics related to BS support equipment and identify relatively 'energy inefficient' sites.
- Smart sites **remote control of passive infrastructure to optimise** energy consumption, Operation and Maintenance (O&M), and Capital Expenditure (CAPEX) planning.
- Identification of energy saving opportunities via **site energy efficiency analysis.**
- **Dynamic thermal management** to control cooling in real-time by balancing the airflow demand with the supplies from the air conditioning units in Core and Data Centre sites.
- **BBU Traffic monitoring** to activate BSs in the extreme dormancy state in realtime.

It should be noted that while automation alone is no silver bullet since it has its own associated energy footprint, the above examples are areas where MNOs have discovered automation to be effective in helping to reduce energy consumption without affecting negatively network performance.

4 As an example, for a like for like upgrade comparing adding a new single band radio to legacy radio vs deploying new multiband radios, we can often achieve a 30% energy reduction (Source: results reported to NGMN by Vodafone).

5 NGMN expects to track this developing area in future reports focusing on metering for sustainable networks.

4.3 IMPROVING COOLING EFFICIENCY: LIQUID COOLING

Cooling systems at a network site, which remove heat generated from the ICT equipment can have a significant impact on the site energy consumption. MNOs have tried to minimise cooling-induced energy consumption using the following techniques:

- Replacing refrigerants with lower Global Warming Potential (GWP) solutions.
- Deploying new cooling technologies that are significantly more efficient.
- Maximising the usage of free cooling, thus guaranteeing minimal consumption.

Regarding cooling solutions, free cooling can be exploited in outdoor sites; however, new cooling technologies are still required for indoor sites (see Section 4.1). In the following subsections, we present in more detail advantages and challenges when deploying liquid cooling technologies.

Liquid cooling technology has been regarded by some MNOs as an efficient way to reduce the energy consumption in the site support equipment room, especially with the increasing concentration of BBU deployments.

In the following, we discuss the four types of liquid cooling technologies available for equipment rooms that MNOs have explored:

- Cabinet liquid cooling: The BBU equipment is placed in the liquid cooling cabinet with liquid cooling pipes on the back of the cabinet. A Coolant Distribution Unit (CDU) and a water pump are used to circulate the liquid in the cooling pipes continuously so that the heat generated by the BBU equipment is absorbed into the liquid of the cooling pipes, then discharged into the atmosphere by the external radiator, resulting in heat dissipation.
- Direct cold plate liquid cooling (DCLC): A liquid cooling pipeline is fixed to a BBU board card. There can be a customised design for different boards, with the liquid cooling pipeline mainly fixed onto a high-power heating device. The coolant is kept flowing uniformly and circularly through the liquid cooling plates of each BBU component to export the heat generated by the heating device through the liquid cooling pipe. The heat generated by the equipment is dissipated by the external heat sink due to heat exchange between the indoor and outdoor environments respectively.
- Immersion liquid cooling: The BBU equipment is immersed directly in the coolant, so that the heat-generating electronic components (e.g., CPU, motherboard, memory module, hard disk, etc.) are in direct contact with the insulating and chemically inert coolant. Thus, the heat generated by these electronic components are dissipated through the circulating coolant.
- Spray liquid cooling: The BBU equipment is placed in a spray cabinet, which is structured in layers. The cooling liquid is stored within the layers of the spray cabinet, with open holes on the top of each layer. The coolant is sprayed directly onto the equipment to allow it to cool.

Table 1 provides a comparison of the four types of the above discussed liquid cooling technologies regarding heat dissipation capabilities, measured in Power Usage effectiveness (PUE), corresponding requirements for the equipment room, and compatibility with existing equipment.[6]

6 Note that the PUE values indicated in Table 1 are typically larger than those reported in literature when presenting recent advancements in cooling applied to data centers, where equipments are usually more concentrated and have higher power consumption, which leads to lower PUE values (around 1.05)

Table 1: Comparison of different types of liquid cooling technologies based on trial and qualitative analysis.

	Cabinet liquid cooling	Cold plate liquid cooling	Immersion liquid cooling	Spray liquid cooling
PUE for a number of BBUs	1.4 (10 BBUs)	1.35 (5 BBUs)	<1.2 (10 BBUs)	
Reliability	Very good	Good – if care is taken to avoid leakage due to corrosion	Good – if care is taken with the optical module and high-speed connectors.	
Maintainability	Very good	Very good	Good - however causticity of the liquid has an impact on installation. Dry chambers are used to prevent contact with the equipment and drip trays are deployed to prevent any room spillage.	
Requirements for equipment room	No requirements	No requirements	Load bearing and space needs consideration	Larger space required
Compatibility	Good	Poor, it cannot be used for existing BBUs	Poor - but can be transformed	

4.4 OPTIMISING BS ENERGY CONSUMPTION

To reduce the energy consumption of the RAN while maintaining stable network KPIs, MNOs have explored the deployment of new RAN equipment with reduced load independent power consumption as well as the optimisation of network capacity according to traffic demand by switching off temporarily underutilised carriers. Time variation and nonuniform spatial distribution of the system traffic results in significant energy waste, because the energy-consuming BS components keep working even when there is no data to transmit. Different levels of BS dormancy are of benefit to varying degrees, often involving turning off part of the active component of Active Antenna Units (AAUs) and of Radio Remote Units (RRUs) in accordance with service requirements, as described in [2].

In this section, we report the energy saving gains that have been achieved deploying carrier shutdown and extreme deep dormancy.

4.4.1 CARRIER SHUTDOWN

Results from China Mobile lab tests and real network tests demonstrated that in zero traffic load scenarios, AAU/RRU carrier shutdown yields power consumption reductions of 20%~50%. It should be noted, however, that extending the lifecycle of BSs - a typical BS lifecycle is approximately 8-15 years - is in conflict with swapping legacy BS components for more energy-efficient solutions. The optimal choice depends on the specific conditions of a site and its associated traffic profile. An example of a carrier shutdown process used by MNOs is described in Figure 3.

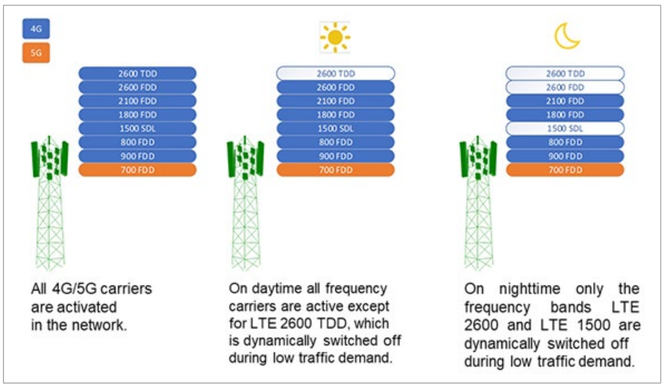


Figure 3: Example of carrier shutdown in 4G network

Figure 4 shows the cell level traffic pattern for both high loaded and low loaded cells and the corresponding power saving window when activating the strategy described in Figure 3. The window size corresponds to the amount of energy that is saved in a cell.

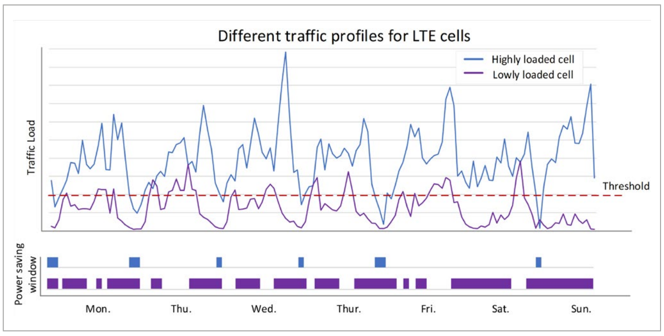


Figure 4: Traffic profiles of 4G cells with corresponding power saving window

4.4.2 EXTREME DEEP DORMANCY

To investigate the possibility of optimising BS energy consumption further, MNOs explored the concept of extreme deep dormancy. Even when the BS is in deep dormancy, the active components of AAU/RRU still consumes dozens of watts of power. To achieve extreme energy saving, the BS could be put in a state of extreme dormancy. This is defined as the state of reduced power consumption achieved by muting all the modules of the AAU/RRU except for the inner auxiliary source, timing module, microcontroller and supporting control circuit of the power supply. The power consumption of the AAU/RRU will be significantly lower when extreme dormancy is activated, and the time that it takes to wake up to normal operations will not be longer than 5 minutes. Tests from China Mobile highlighted that there was not any drop rate when users were transitioned to the coverage cell. Nevertheless, the 5 minutes wake up might be a limiting factor for MNOs to implement this feature. Adoption could be greater if the wake-up time were to be reduced.

Current BSs support extreme dormancy based on a predefined timing setting, as well as real-time wake-up/sleep modes through BBU traffic monitoring. The latter approach is more flexible and efficient for energy saving while avoiding potential service quality degradation but requires certain dedicated hardware to receive wake-up signals from the BBU.

05 ENSURING ENERGY STABILITY

The second pillar of the MNO response to the energy challenge is to ensure energy stability against a backdrop of energy supply, so that quality of service (QoS) could be maintained. MNOs have proactively worked towards ensuring a resilient and affordable energy supply using the following methods:

- Responding to calls for load shedding preparations and power cut/outage management during winter.
- Deploying equipment for production of renewable energy.
- Leveraging hydrogen, ammonia and fuel cell technologies to produce carbon-free energy.
- Optimising battery usage for RAN sites.
- Improving the resilience of the electrical network and avoiding unnecessary electricity expenses through energy flexibility initiatives.

5.1 RENEWABLE ELECTRICITY GENERATION AND BATTERY STORAGE

For MNOs, renewables are a key initiative to leverage onsite power generation to reduce the power from the grid, as well as reduce carbon emissions from diesel generators for off-grid RAN sites.

To maximise onsite electricity generation, MNOs are evaluating the possibility of using solar and wind together. Wind energy may complement solar energy and the energy generated from both can be stored in batteries, which can be used when neither solar nor wind is enough to meet energy demand or during energy consumption peaks. Unfortunately, both energy production technologies still have high deployment costs, and only some sites are suitable for renewable implementation due to limiting factors e.g., shading, space, wind speed, etc. Moreover, it may be difficult to obtain the necessary permits, whereby these may also require long waiting times to be granted by local regulators.

MNOs have sought innovative solutions to the challenge of generating renewable power directly at RAN sites in rural or remote areas without access to power grids or where there are frequent power outages while avoiding using fossil fuels onsite.

Together with renewables, the deployment of battery equipment on site, is key to ensuring continuous service and maximising the usage of renewable sources. Electricity networks in advanced markets have been assumed to be stable and resilient based on historical records demonstrating many years of largely uninterrupted supply. This has led to a reduction in backup solutions onsite, leading to increased dependency and vulnerability to grid outages. Today, MNOs are deploying more back-up battery capacity as a smarter way to reduce dependence on electricity grids.

Both the RAN and Core network infrastructure can be equipped with batteries, and in some cases, even with generators or fuel cells offering protection against vulnerability to power outages. While this initiative does not necessarily save energy alone, it does support MNO business continuity plans to guarantee QoS for customers.

5.2 OPTIMISING BATTERY BACKUP AUTONOMY

Maintaining uninterrupted service to customers in the face of energy supply risks necessitates improving energy backup autonomy for RAN sites. The energy backup situation varies significantly across markets. In markets with good quality in energy supply, the majority of RAN sites have a battery lifetime ranging from approximately 15 to 30 minutes. By activating intelligent energy saving features, e.g., using the Operational Support System (OSS) through "cell switch-off," the required power can be reduced, subsequently increasing battery autonomy, while maintaining stable KPIs [2].

The energy consumption of RAN sites has increased due to capacity upgrades, often involving the addition of new radios on the same site to cater to growing traffic demands. This introduces the concept of "radios for coverage" and "radios for capacity," where coverage bands provide better propagation conditions, encompassing frequencies up to 900 MHz for example, while capacity bands have a large amount of available resources, typically including frequencies above 900 MHz (see Figure 5). To address energy crisis scenarios, a gradual switch-off of frequencies from capacity bands to coverage bands can be implemented. For example, a sequential switch-off order can operate as follows: 2.6 GHz, 2.1 GHz, 1.8 GHz, and finally 700 GHz, where each respective carrier frequency is switched off in turn, depending on traffic conditions.

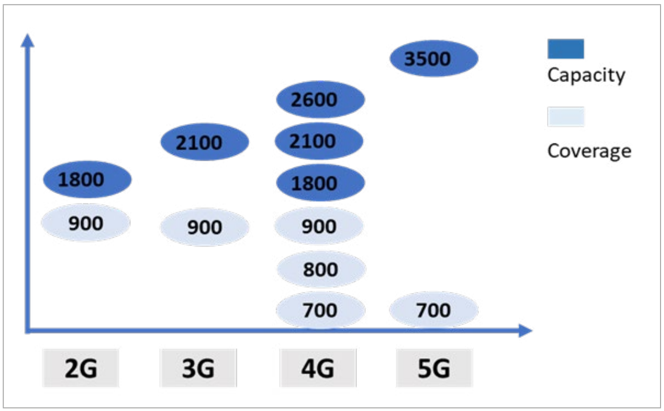


Figure 5: Example of capacity and coverage bands for different RATs

The "cell switch-off" feature, when used to deactivate a carrier frequency, can yield a potential power gain of approximately 100W-200W per frequency per site (across 3 sectors).[7]

However, the potential gains from frequency band switch-off may not be substantial due to the inherent limitations in completely turning off the power amplifiers (PAs). This is because a single PA commonly handles multiple frequencies. This is generally a more energy efficient approach than using a distinct PA per frequency band during running time but it places a ceiling on how much power reduction through frequency band switch-off alone can be achieved [2].

Moreover, complete powering down of the PAs is not feasible when rapid wake-up is required for ensuring uninterrupted service availability. Moreover, the energy saving gain is highly dependent on the traffic load and the type of radio modules employed on the site, including factors such as the product type, generation, and multi-band capability.

Furthermore, even when cells are switched off, equipment such as RRUs continue to consume significant energy. Additional savings (approximately 150 W/RRU) can be achieved by completely switching off the equipment.[8] However, remote and automated switching off of equipment is currently not possible due to the need for additional hardware and the requirement to address potential reliability issues.

The deployment of smart circuit breakers allows remote and automated switch-off of capacity cells in order to provide up to six hours of autonomy, for example in voice services operating on the 700 MHz frequency band.

5.3 IMPROVING THE NETWORK ENERGY FLEXIBILITY

Energy flexibility refers to the ability to adapt electricity generation and/or consumption for a specific period to contribute to the supply-demand balance of the electricity system. It offers several benefits, including reducing energy bills, optimising the utilisation of renewable energy, participating in the electricity market to support grid stability, and leveraging storage investments.

7 Source: Analysis reported to NGMN by Orange.

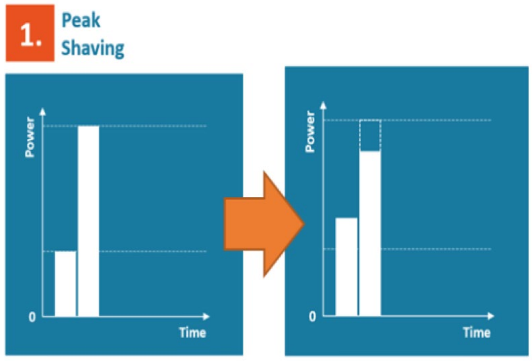
8 Source: Analysis reported to NGMN by Orange.

For MNOs, there are implicit and explicit solutions to valorise flexibility actions:

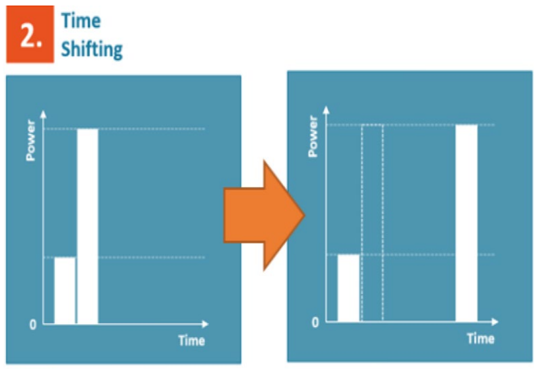
- **Implicit energy flexibility:** MNOs are encouraged to regulate their power consumption to optimise their bills by leveraging dynamic electricity tariffs. These tariffs may range from simple day and night prices to highly dynamic prices based on hourly wholesale prices. Implicit flexibility can be implemented in various ways, through e.g., automated software, including Peak Shaving, Time Shifting, and Flexibility in Time and Amount, as depicted in Figure 6.

- **Explicit energy flexibility:** MNOs can also benefit from flexibility individually, either by selling energy blocks in wholesale markets or through contracts with aggregators.

Energy flexibility opportunities can be explored across various energy assets, including networks, tertiary sites, Electric Vehicle (EV) fleets, and clients' domains. Among the identified scenarios, leveraging backup batteries in network assets - or even deploying additional batteries - has been found to be the most profitable and mature option. A detailed case study could be considered for exploring different mechanisms, for example, time-shifting using Li-ion batteries on RAN sites.



Peak shaving will reduce demand or production at the critical moment in time and will add this to demand or production at another moment in time when this is more optimal for the portfolio of the gird operator.



Time shifting will postpone the demand or production at the critical moment in time and will activate this demand or production at another moment in time when this is more optimal for the portfolio of the grid operator.

Flexibility in time and amount is a combination of both peak shaving and time shifting.

Figure 6: Types of implicit solutions for energy demand side flexibility

06 BEST PRACTICE

Reducing energy usage now is more important than ever. In this report, we have described how MNOs have taken smart measures at an accelerated pace to further reduce energy consumption in the short term, while simultaneously maintaining desirable network QoS and handling a continuous increase of data traffic volume:

- Accelerate the transition from legacy networks (e.g. 2G and 3G) to more energy efficient technologies (e.g., 4G and 5G) whenever possible.
- Deploying additional 5G/4G spectrum refarmed from 3G to increase network data throughput and capacity, and to keep up with the high data growth experienced during the past years.
- Leveraging the capabilities of the latest RAN technologies to achieve higher energy efficiency.
- Implementing Intelligent RAN energy saving features to save more energy in both 4G and 5G layers.
- Updating RAN sites with state-of-the-art energy efficient RAN equipment and antennas which facilitate all mobile generations, 2G to 5G.
- Replacing all onsite airconditioning units with energy efficient cooling.
- Deploying renewable energy sources and battery storage units, which reduce the network dependency by electrical grids.
- Use intelligent energy saving features together with battery storage equipment to further increase the network stability.

For example, deployment of some of these solutions has allowed KPN to keep energy consumption flat over the years 2018-2022, while data traffic did increase by 33% annually. Similarly, in the past five years, in the Vodafone network, data traffic has increased over 600% yet the absolute energy consumption has not changed, representing a reduction of energy consumed per unit of data traffic of nearly 90%.

Besides these best practices, we have identified in this publication relevant constraints that limit the adoption of energy saving features and equipment leading to improved energy efficiency, specifically:

- The adoption of extreme dormancy features could be greater if the BS wake-up time could be reduced.
- The target of extending the BS lifecycle is in conflict with swapping legacy BS components for introducing more energy-efficient solutions.
- Potential energy saving gains from frequency band switch-off may not be substantial due to the inability in completely turning off the multi-carrier Pas.
- Deploying renewable energy solutions could be accelerated if the process for obtaining the necessary permits could be simplified.

07 ABBREVIATIONS

AAU	Active Antenna Unit
AI	Artificial Intelligence
BBU	Baseband Unit
BS	Base Station
CAPEX	Capital Expenditure
CDU	Coolant Distribution Unit
CO2	Carbon Dioxide
CPU	Central Processing Unit
CU	Centralised Unit
DU	Distributed Unit
EC	European Commission
ETS	Emissions Trading System
EU	European Union
EV	Electric Vehicle
GHG	Greenhouse gas
ICT	Information and Communication Technology
IoT	Internet of Thing
IPCC	Intergovernmental Panel on Climate Change
ISV	independent Software Vendors
KPI	Key Performance Indicator
MIMO	Multiple Input Multiple Output
ML	Machine Learning
MNO	Mobile Network Operator
O&M	Operation and Maintenance
OSS	Operational Support System
PA	Power Amplifier
PRB	Physical Resource Block
PUE	Power Usage Effectiveness
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RRU	Remote Radio Unit
SSE	Site Energy Efficiency
TDP	Thermal design power

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NEXT GENERATION MOBILE NETWORKS ALLIANCE

NGMN, established in 2006, is a global, operator-led alliance of over 80 companies and organisation spanning operators, manufacturers, consultancies and academia.

VISION

The vision of the NGMN Alliance is to provide impactful guidance to achieve innovative and affordable mobile telecommunication services for the end user with a particular focus on supporting 5G's full implementation, Mastering the Route to Disaggregation, Sustainability and Green Networks, as well as 6G.

MISSION

The mission of the NGMN Alliance is

- To evaluate and drive technology evolution towards 5G's full implementation and the three major priorities for 2021 and beyond:

  Route to Disaggregation: Leading in the development of open, disaggregated, virtualised and cloud native solutions with a focus on the end to end operating model.

  Green Future Networks: Building sustainable and environmentally conscious solutions.

  6G: Emergence of 6G highlighting key trends across technology and societal requirements plus use cases to address.

- to establish clear functional and non-functional requirements for mobile networks of the next generation.
- to provide guidance to equipment developers, standardisation bodies and cooperation partners, leading to the implementation of a cost-effective network evolution
- to provide an information exchange forum for the industry on critical and immediate concerns and to share experiences and lessons learnt for addressing technology challenges
- to identify and remove barriers for enabling successful implementations of attractive mobile services

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