Network Energy Efficiency Phase 2

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NETWORK ENERGY EFFICIENCY PHASE 2

by NGMN Alliance

Version:	1.0
Date:	10.10.2023
Document Type:	Final Deliverable (approved)
Confidentiality Class:	P - Public
Project:	Green Future Networks
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NGMN Programme Office:	Chris Hogg, representing NGMN
Approved by / Date:	NGMN Alliance Board, 15 August 2023

EXECUTIVE SUMMARY

Electricity – even if generated from renewables – is a finite resource and is a significant operating input cost to mobile networks. It is therefore important to reduce electricity consumption by making networks more energy efficient. The recent energy crisis has created further emphasis on this issue.

The mobile industry through the NGMN Alliance's (NGMN) Green Future Networks Programme has come together to find solutions to increase network energy efficiency and enable operators to reduce their electricity consumption. In this publication we outline and prioritise the various options available to increase network energy efficiency. In particular energy saving approaches are organised into three broad categories (and time-horizons): (short-term) process optimisations; (medium-term) engineering optimisations; and (long-term) new technologies. Our results highlight that it is possible – in the short term - to reduce energy consumption by up to 10% by optimally configuring networks to use existing power saving features. To do this, Machine Learning (ML) can be used to estimate the energy consumption reduction that can be brought by existing power saving schemes and thus support the process to determine the most appropriate energy saving policy to deploy. Further energy savings are possible in the medium-term by investing in cell site upgrades and redesigns that reduce energy consumption in key components and maximise the conversion of electrical energy to Radio Frequency (RF) energy. Given that the Radio Access Network (RAN) accounts for around three-quarters of all mobile network electricity consumption [1] with the base station equipment, composed by Radio Unit (RU), Baseband Unit (BBS), and Main Control accounting for half of the electricity consumption of a typical cell site (figure 1), a 30-40% energy saving per RU could result in an energy saving of around 12% across the RAN.

In the medium to longer-term mobile operators will need to invest in new technologies to gain further energy savings. Of particular interest – given that cooling accounts up to 40% of RAN energy consumption – is both Direct Contact Liquid Cooling (DCLC) and liquid immersion cooling. Advanced technologies such as Reconfigurable Intelligent Surfaces (RIS) and Distributed (cell-free) Massive MIMO could in the longer term offer further gains in relation to network energy efficiency.

A full prioritised list of energy saving solutions is available as a table in chapter 5 'Recommendations'.

NGMN recommends that operators review the energy saving potential of each option offered in this publication and that further studies are conducted regarding the energy saving potential of key technologies such as network disaggregation and cloudification. Additionally, studies should be undertaken to review the state of the art in energy management and renewable energy solutions.

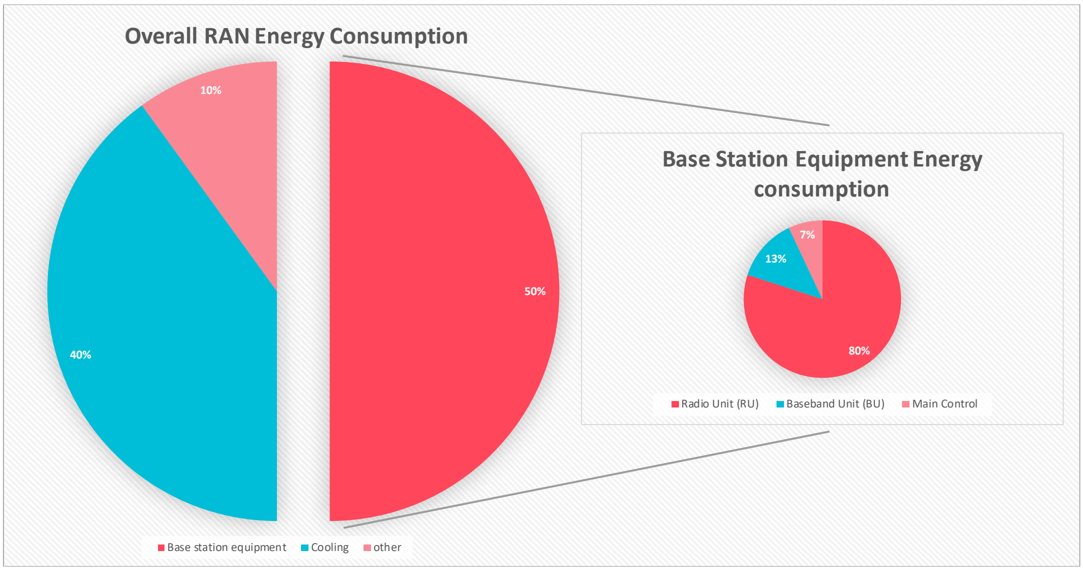

Figure 1: Breakdown of RAN Energy Consumption [1]

CONTENTS

01 INTRODUCTION

The mobile industry through the NGMN Alliance´s (NGMN) Green Future Networks Programme has come together to find solutions to increase network energy efficiency and enable operators to reduce their electricity consumption. In this publication we outline and prioritise the various options available to increase network energy efficiency. In particular energy saving approaches are organised into three broad categories (and time-horizons):

- (short-term) process optimisations (chapter 2)
- (medium-term) engineering optimisations (chapter 3)
- (long-term) new technologies (chapter 4)

For each energy saving approach information is provided – based on data from live networks and/or simulations – on the size and scope of the potential energy savings.

The publication builds on NGMN's first Network Energy Efficiency report which reviewed where energy is consumed in a typical mobile network and highlighted opportunities and challenges for the industry to improve network energy efficiency [1]. As identified in that first NGMN report, the vast majority of electricity consumption (almost three-quarters of all energy consumed) is in the mobile sites. For this reason, many of the solutions proposed seek to – as a priority – minimise energy consumption in the RAN. However, energy consumption in the operators' data centres is also addressed in relation to issues such as cooling technologies and the move towards virtualised and cloud-native network elements.

02 DATA-DRIVEN ENERGY CONSUMPTION OPTIMISATION

Due to the energy crisis, operators are faced with immediate challenges from soaring operational expenses as a result of higher energy costs. Optimising processes and optimally configuring the network to meet traffic demand can enable operators to make immediate energy savings with minimal investment in new infrastructure, software, and services. In this section we describe how such optimisation can lead to energy savings. To maximise impact, our focus is on tools and technology that are widely available as a result of ongoing standardisation initiatives.

2.1 NETWORK ENERGY SAVING FEATURES SUPPORTED BY 3GPP STANDARDS

During previous releases, 3GPP has focused on both UE power saving [2] and network power consumption reduction. Currently, in 3GPP 5G-Advanced Release 18 and 19, there is an increasing focus on reducing energy consumption in the network. The RAN is identified as the primary contributor to energy usage, and thus various features are being defined to minimise energy consumption in the RAN by making more efficient use of radio resources particularly in low/medium load scenarios [3] [4] [5]. Among others, 3GPP Release 18 is defining cell discontinuous transmission and reception (cell DTX/DRX) and extensions to SSB-less Serving-cell (SCell) operations to reduce the signalling/data (and thus processing) load on the cell as well as spatial and power domain adaptations to dynamically control the active mMIMO antennas, and PDSCH transmit power based on the actual needs. The aim is to achieve energy saving by switching off hardware components while minimising the impact on user equipment and network performance. Additionally, the use of AI/ML algorithms is being explored by 3GPP to optimise energy-saving solutions [6]. By utilizing RAN data, these algorithms can predict cell loads and states, enabling tailored and energy-saving actions such as traffic offloading and dynamic sleep modes. The normative work for these developments is ongoing. Beyond the RAN, 3GPP is also looking at architectural enhancements and new use cases for system energy efficiency [7]. Using these features together with more energy efficient network equipment can lead to large energy saving gains. However simply turning on these features in the network is not enough – the impact of these features on the energy consumption must be understood, and the features must be correctly configured in order to ensure network performance is not compromised for end-users.

2.1.1 DATA-DRIVEN MODELLING OF RADIO UNIT (RU) POWER CONSUMPTION

Modelling the impact of different energy saving features on the power consumption of the RU is key to optimise the radio access network. 3GPP has recently defined an RU power consumption model for evaluation purposes [4]. The model characterises the power consumption of the RU on a per slot basis for different configurations. Specifically, the model defines the power consumed by the base station, while in asleep state and active state. Another model has been proposed in [8] to capture the relationships between the key components that play a major role on RU power consumption.

In [8] a machine learning (ML) framework has been designed and trained to gather knowledge from many different types of RU with different hardware configurations, and potentially from different vendors [8]. Figure 2 shows that the analytical model in [8], fitted by the ML framework can accurately describe the RU power consumption during running time, and including the effect of power saving features. Notably, this modelling approach allows, taking advantage of the ML generalization properties, to cover scenarios that may not be directly observable in the collected data but that are needed to derive the proposed analytical model.

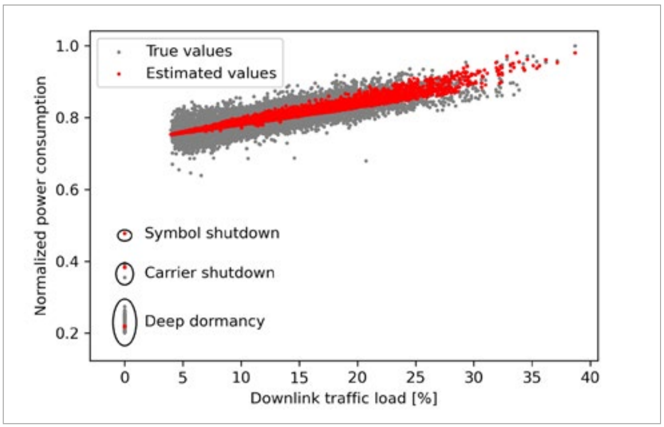

Figure 2: Normalised Radio Unit (RU) power consumption vs downlink traffic load, estimated by the fitted analytical model [8]

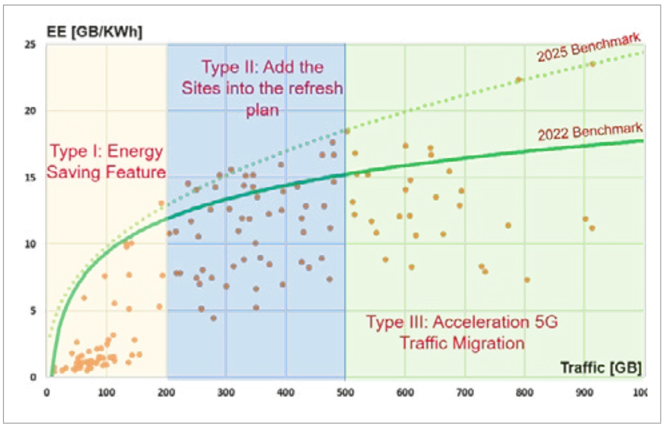

Figure 3: Network energy efficiency benchmarking

2.1.2 DATA-DRIVEN SITE REFRESHMENT AND NETWORK ENERGY SAVING FEATURE ACTIVATION OPTIMISATION

In this section, we provide an example of using a data-driven framework to optimise energy efficiency in a real network covering a European metropolitan area. First of all, cell-level statistics were collected from 168 BS sites in the area of study, and for each site we compute a QoS-adjusted energy efficiency metric:

Energy efficiency =
(Data volume / Energy consumption) × Factorrate
where
Factorrate =
Average downlink rate / Average target downlink rate

As will be seen, this QoS-adjusted energy efficiency metric allows for a more comprehensive energy efficiency evaluation, which reflects the investment of MNOs to improve QoS in the 5G era, which is beneficial for network optimization.[1]

Figure 3 illustrates the QoS-adjusted energy efficiency metric computed for each of the 168 BS sites in the area of study, where every orange dot represents one BS site, and the green lines represent current and future energy efficiency benchmark curves to enable optimisation while considering traffic and network changes over time.

After this evaluation process, comparing the site QoS-adjusted energy efficiency with the 2022 benchmark curve, low energy efficiency BS sites were identified and divided in three groups of interest:

- Type I: Low traffic and high downlink rate, where network energy saving solutions are not fully utilised/activated.
- Type II: High traffic and low downlink rate, where energy saving solutions are fully utilised, and the hardware efficiency can be improved.
- Type III: High traffic and high downlink rate, where energy saving solutions are fully utilised, and the hardware is new.

For type I BS sites, the QoS-adjusted energy efficiency metric can be improved by activating energy saving solutions more aggressively. For type 2 sites, the QoS-adjusted energy efficiency metric can be improved by hardware refresh. For type 3 sites, the QoS-adjusted energy efficiency metric can be improved by migrating traffic towards 3rd generation partnership project (3GPP) new radio (NR) cells, e.g. from 3GPP long term evolution (LTE) to NR. In this report, we present results on optimisation for type I BS sites and type 2 sites. We will focus on type 3 sites in a future report.

In our trial, we were able to save 1473.5 kWh per day for type I BS sites with respect to the baseline through the activation of optimised energy saving solutions (described in Table 1) while maintaining stable key performance indicators (KPIs) related to network performance and UE service quality, which, overall, led to improve the QoS-adjusted energy efficiency metric for these types of cell site by 17.5%.

[1] In this simple example, a QoS factor based on the user perceived rate was introduced, but one could also envision to formulate QoS factors for metrics, e.g. coverage, delay or even combinations thereof.

Among type II BS sites, we selected two specific BS sites to quantify the gains obtained by hardware refreshment, replacing RUs and BBUs with more efficient multi-band equipment. This process indicates that refreshment, not only can lead to an up to 41% energy saving gain per BS site (from 63 to 37 kWh), but also can improve the UE rate up to 100% (from 14 to 28 MBps), which results to improving the QoS-adjusted energy efficiency metric by up to 260%.

Table 1: Baseline and updated energy saving feature for type I sites

RAT	Feature	Power Saving Solution (Main)
LTE	Symbol Power Saving (LTE-FDD)	Enabled on all cells
	Deep Symbol Power Saving	Enabled on all cells
	Energy Saving Based on Proactive Scheduling	This feature is enabled when the load is light and all LTE cells on the RRU do not have mutually exclusive features
	RF Channel Intelligent Shutdown	Retain the original configuration
	Intelligent Power-Off of Carriers in the Same Coverage	For cells that have been active before, change the threshold to 30 threshold + 20 offset Extend feature time to 0-16 For cells that have not been activated before, select 1800 MHz as the basic layer and 2600 MHz as the capacity layer with light load Set the threshold based on the load Set feature time as 0-24
NR	Symbol Power Saving	Enabled on all cells
	Intelligent Scheduling	Enabled on all NR cells Set the threshold based on the load Set feature time as 0-24
SRAN	Multi-RAT Coordinated Symbol Power Saving	This feature is enabled when LTE and NR cells share the same RRU
UMTS	RRU Intelligent Dormancy	Above world (~40%) and/ or country average
GSM	Enhanced BCCH Power Consumption Optimization	Retain the original configuration

2.1.3 DATA-DRIVEN OPTIMISATION OF NETWORK ENERGY SAVING FEATURES

Traditionally, optimising a network required drive tests to be undertaken to gather statistics on network use. Today AI/ML enhanced network simulation using data collected from customer devices in the network together with models of the radio environment and mobile network configuration can lead to more insightful results without the need to commission drive tests [9] [10]. The basic principle of using models is that data (from user devices and from the network) are fed into an algorithm that uses an iterative process to find the optimum network configuration settings that will lead to energy saving whilst maintaining a pre-defined service quality. The results of the algorithm can then be used to configure the network for optimum energy saving. This process is depicted in figure 4.

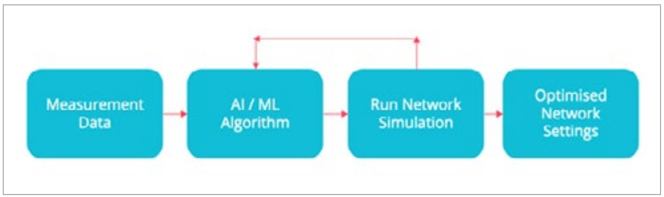

Figure 4: Data Driven Network Optimisation using AI/ML and/or 'white-box' models

2.1.3.1 EXAMPLE APPLICATION OF DATA-DRIVEN NETWORK OPTIMISATION

In preparing this report, NGMN was presented with an example of using data-driven network optimisation in a real (4G/5G) network covering a large metropolitan area. The network comprised of 4G (multiple frequency bands) and 5G-NR (using a single frequency band). In all cases the 4G and 5G frequencies were provided from the same radio unit (RU) using wideband power amplifiers making network energy efficiency optimisation even more challenging, as the deactivation of one of the cells powered by the wideband power amplifiers (PAs) – there is one wideband PA per radio frequency (RF) chain– of a wideband RU may not bring any energy saving, if the wideband PAs need to remain active to operate other co-deployed active cells.

Three phases were conducted in this trial, which are summarised in Table 2. Note that more than three weekdays were used to collect data for each phase.

During the first phase, in order to estimate the baseline network energy consumption, all the power saving solutions, i.e. symbol, RF and carrier shutdown as well as deep dormancy were deactivated and field network performance datasets were collected.

During the second phase, shutdown solutions were tuned and activated following a traditional rule-based approach, mainly based on system-level simulations and the frontline engineer expert knowledge.

For the last phase, the proposed network energy efficiency optimisation methodologies were applied to optimise system-level parameters, including coverage and capacity cell pairing, shutdown solution thresholds as well as the periods of the day in which the solutions can operate. Related handover parameters were also optimised.

Table 2: Energy saving features for each phase

Power Saving Features		Phase I (Baseline)	Phase II (Rule Based)	Phase III (Optimised)
4G cells	Symbol shutdown and scheduling	Deactivated	All hours	All hours
	LTE channel shutdown	Deactivated	0~6 hours	Optimised
	LTE carrier shutdown	Deactivated	0~6 hours	Optimised
	Deep dormancy	Deactivated	0~6 hours	Optimised
5G cells	Symbol Shutdown and scheduling	Deactivated	All hours	All hours
	NR channel shutdown	Deactivated	0~6 hours	Optimised
	LNR carrier shutdown	Planned	Planned	Planned
	Deep dormancy	Deactivated	0~6 hours	Optimised

2.1.3.2 POTENTIAL ENERGY SAVINGS FROM DATA-DRIVEN NETWORK OPTIMISATION

Comparing the baseline energy consumption, the rule-based approach was able to save 245 kWh per day in the considered scenario, which translates into a 3% energy saving gain. When considering the proposed network energy efficiency optimisation methodologies, traffic was migrated towards the most energy efficient cells, allowing others to use shutdown solutions for a longer period of time. As a result, with respect to the baseline and rule-based approaches, this more sophisticated approach was able to save 1000 and 755 kWh per day in the considered scenario, respectively, i.e. a 12 and 9.1% energy saving gain, respectively. Importantly, the figure shows how, at the same time, key performance indicators related to UE service quality, i.e. the average UE rate and the percentage of users in good coverage (above -105 dBm) y, are minimally impacted.

Although we have focused on a 4G / 5G example the data driven network optimisation is equally applicable to other technologies (e.g. 2G/3G).

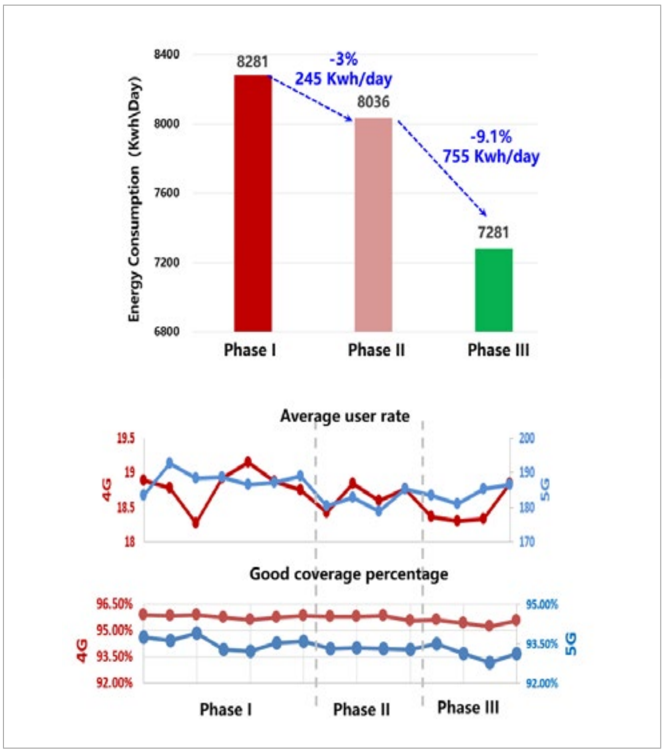

Figure 5: Energy saving and KPI performance for each optimisation phase

03 ENGINEERING OPTIMISATION

In addition to process optimisation, there exists a wide range of engineering optimisations that operators, working with their infrastructure and services partners, could implement to further increase the energy efficiency of the network. This section looks at three major areas that can be addressed by operators in the short to medium term.

3.1 RADIO, BASEBAND AND ANTENNAS

As the RAN consumes almost three-quarters of the energy in a mobile network improving the energy efficiency of the RAN is of critical importance to deliver energy savings [1].

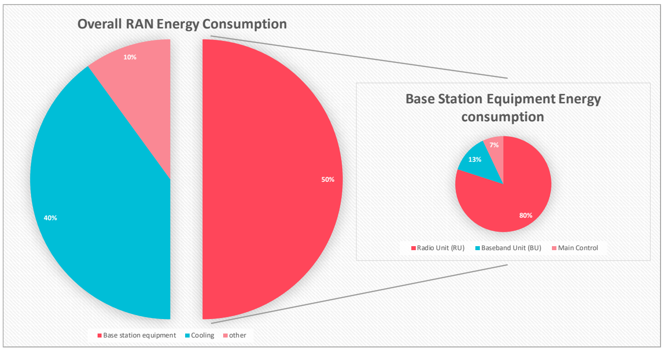

Figure 6: RAN Energy Consumption [1]

Figure 6 shows that the largest part of energy consumption in the RAN (at least 50% of overall energy consumption) is the base station equipment (RU, BU and control equipment), whilst the RU comprises the largest contributor to the energy consumed by the base station equipment. The analysis in Table 3, considering a whole national network composed by various types of equipment, further shows that in 5G the contribution of the RU is nearly 90% of the energy consumed by the base station equipment (compared with the 80% in 4G) [11].[2] To save energy in the RAN it is therefore imperative to consider how to save energy in the RU. Reducing energy consumption in the baseband and minimising losses in the radio channel through improvements in antenna design are also important considerations.

[2] Note that the main control power consumption is not reflected in this study.

Table 3. RU and BBU measured power usage split in a whole national network [11]

	5G Power Usage	4G Power Usage
RU	88%	82%
BBU	12%	18%

3.1.1 RADIO UNIT ENERGY CONSUMPTION

RU energy consumption depends on several factors. Figure 7 shows the power usage of various types of RUs in idle mode. As can be seen, on the whole 5G AAUs power consumption is larger than that of LTE RRUs mostly because AAUs have 8 times more RF channels, 5 times wider bandwidth, and larger transmit powers. For instance, the analysis carried out in [12] shows that a 5G RU operating with 100 MHz, 64 antennas, and 240W maximum transmit power consumes 4077 W while a 4G RU operating with 20 MHz, 8 antennas, and 40W maximum transmit power consumes 950 W. The figure 7 also shows that the 5G AAU power consumption and transmit output power significantly vary, even when considering equipment with the same number of antennas. Such variation is not present in 4G RRUs.

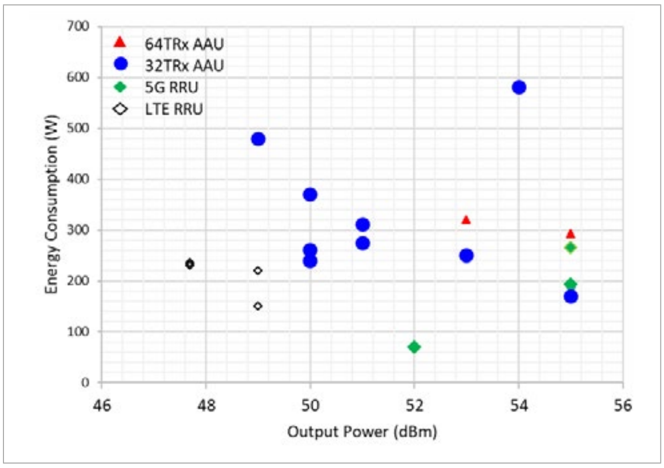

Figure 7: Transmit Power (dBm) versus Power Consumption of various RRU / AAU configurations [11]

Energy Consumption in RRU / AAU can be classified into two major categories:

- the **static energy consumption,** which does not depend on the traffic serviced by the RRU/AAU. The number of RF transceiver chains supported by the RRUs/AAUs is the most important feature impacting the static energy consumption, as it drives the number of multi-band power amplifiers (PAs) required by the RRUs/AAUs.

- the **dynamic energy consumption,** which, in contrast, depends on the traffic load of the RRU/AAU, and by the maximum transmit power of the equipment.

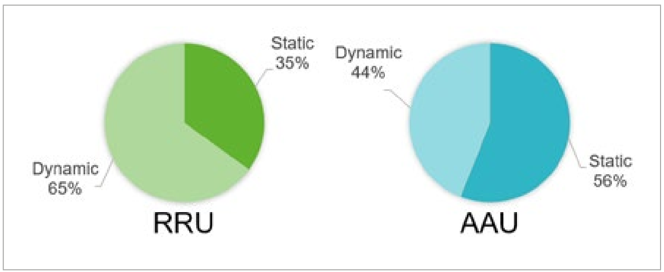

Figure 8: RRU and AAU energy consumption [11]

Figure 8 show that the static energy consumption of an RRU accounts for 35% of its total energy consumption, while that of an AAU represents 56%. The increased static energy consumption in the AAUs emanates due to the increased amount of hardware used to support and drive the massive MIMO beamforming and spatial multiplexing capabilities.

3.1.1.1 IMPROVING RRU / AAU ENERGY EFFICIENCY

To increase the energy efficiency of RRUs, one may consider (i) increasing the number of supported transmit and received chains, (ii) adopting multi-band PAs and (ii) allowing them to share their transmit power between the supported frequency bands. **As an example, an energy saving of around 30% should be possible in the case of moving from single band RRUs to tri-band RRUs.**

Increasing the number of transmit chains gives better coverage and capacity. Going from 2T to 4T adds diversity gains and going to 8T enables beamforming as well as sector split. All in all, the total gain can be as much as 60% reduction in transmit power, which in turns reduces the energy consumption of the RRU significantly.

Increasing the number of antenna elements per PA in an AAU (i.e. increasing the 'antenna gain' of the AAU) can significantly increase network energy efficiency. **Trials with double the amount of antenna elements in the vertical direction show that an energy saving of up to 30% per AAU can be achieved under realistic network and traffic scenarios.**[3]

3.1.2 BASEBAND UNIT (BBU)

After the RU, the next most energy hungry part of the base station equipment is the Baseband Unit (BBU) – accounting for around 13% of the overall base station equipment energy consumption. Similar to our analysis of the RU, the energy consumption of a BBU can be split into static consumption (which is independent of traffic load) and dynamic consumption (which increases with traffic load). Using a single BBU to serve multiple cells can therefore reduce energy consumption (as the static consumption is pooled over more cells). However – as seen in figure 9 – there is wide variability in energy consumption in different types of BBUs.

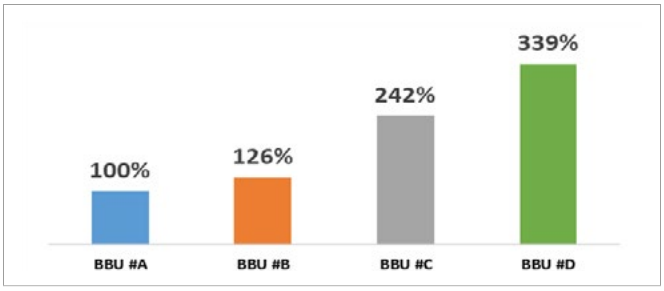

Figure 9: BBU energy consumption per cell under normalised conditions BBU #A is taken as baseline with energy consumption of other BBUs reported with reference to the baseline [11]

This is likely due to differences in the type and number of features implemented in the BBU as this impacts the digital signal processing that each BBU must carry out and therefore the energy consumed. For instance, BBUs based on a general-purpose server have distinct power consumption than BBUs based on dedicated components. In addition, since the energy consumption of BBU is affected by traffic load and power consumption in each component, any relevant software features for reducing energy use and minimising any performance degradation can make a large difference: features as cell off, channel card off, and model off will reduce the BBU's energy consumption. These results highlight that there is a room for improving BBUs energy efficiency.

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[3] Source: https://www.huawei.com/en/news/2023/2/mwc2023-best-mobile-network-infrastructure

3.1.2.1 IMPROVING BBU ENERGY EFFICIENCY

BBU energy consumption could be reduced by:

1. Using deep dormancy modes (if available) to switch off the BBU when there is no traffic in the cell.

2. Using Network Function Virtualisation: By disaggregating the BBU into a central unit (CU) and a distributed unit (DU) energy can be saved by pooling the CU resources in the cloud / data centre and sharing these resources between multiple cell sites.

At present, we have no data regarding the extent to which the different approaches outlined above can reduce BBU energy consumption. This is for further study.

3.1.3 PASSIVE ANTENNAS

Antennas convert electrical energy (modulated signals) into electromagnetic energy (radio waves). Passive antennas – as the name implies – do not consume any electricity however the efficiency with which they convert the electrical energy to radio waves is relevant to the overall energy consumed in RAN.

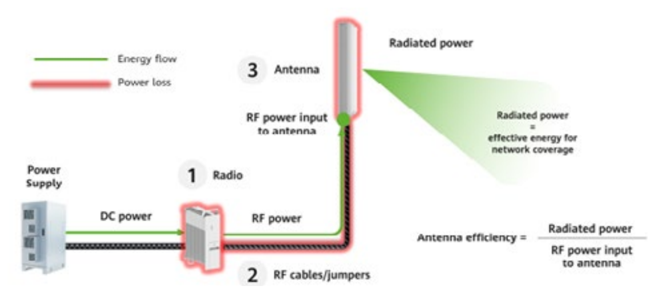

Figure 10: Diagram of energy flow in a base station utilizing a remote radio unit and passive antenna

There are three main losses in passive antennas:

- **Return losses:** these are losses due to electrical impedance mismatch between the RU and the antenna.

- **Insertion losses:** Energy lost as heat inside the antenna.

- **Coverage losses:** Losses due to the difficulty in directing RF energy to the desired region (e.g. due to the presence of side lobes in the radio signal).

Various metrics exist to describe these losses; however the most important overall measure is that of antenna radiation efficiency:

Antenna radiation energy efficiency = energy output by the antenna / energy input to the antenna

3.1.3.1 IMPROVING PASSIVE ANTENNA EFFICIENCY

Improving passive antenna efficiency requires to address the main losses outlined in the previous section.

- **Simplify the feeding paths:** In a traditional antenna architecture, the feeding network generally includes components such as phase shifters, power splitters and combiners, all of which are connected by coaxial cables. After entering the antenna RF port, an RF signal travels along a complex path inside the antenna to finally reach the dipole array, which generates the electromagnetic wave radiation. Complex feeding paths dissipate RF energy. Energy loss is related to the frequency band of operation. Typically, this loss is about 25% on low frequency bands (< 1GHz), and about 35% on mid frequency bands (1.7 – 2.6 GHz). An antenna with a typical configuration (2 low bands / 4 high bands) would experience losses due to the complex feeding path of around 30%. Simplifying the feeding network (for example by combining all the distribution components into one, reducing the number of component connections, and replacing co-axial cables with air type strip lines) can reduce the overall loss to about 17% (down from 30%) for a typical antenna configuration (2 low bands / 4 high bands). This represents an almost 50% reduction in feeding path losses.

- **Using high quality/new materials for the dipoles and radome:** The dipoles convert the electrical energy to electromagnetic (radio) waves whilst the radome is the enclosure for the dipoles. Both components impact the overall antenna energy efficiency. For the typical configuration described earlier (2 low bands / 4 high bands) using die-cast dipoles results in losses of <1% whereas using a high-quality substrate losses increase to around 1.5%. Using poorer quality substrates (e.g. FR4 epoxy) can result in losses up to 10%. Likewise present radomes are mostly constructed from fiberglass resulting in losses of around 5%. Using new materials can half these losses (to 2%).

- **Reduce RF cabling losses:** Energy losses in feeders, jumpers (flexible co-axial cables between the RRU and the antenna) and connectors can be reduced by re-designing the site so as to reduce the cable lengths. As an example, at 2.1GHz the RF energy loss over a 4-metre jumper cable is 11%. New designs, where the RRU is located much closer to the antenna could enable jumper cables of around 0.3 metres, significantly reducing cabling losses. In 5G sites supporting both FDD and TDD bands using cluster connectors can enable the lowest RF path insertion losses.

- **Integrate RRU and AAU (hybrid solutions):** In sites supporting both 4G and 5G it is possible to integrate the RRU and AAU into a single unit behind the passive antenna (which is used by the RRU). Locating both the hybrid RRU/AAU at the same height on the tower as the passive antenna enables better coverage for the radio (5G) that is being added (or moved) on the tower. This helps to reduce 5G coverage losses and thereby reduces the energy needed to maintain a given coverage.

3.2 REDUCING DC POWER LOSSES

The DC power distribution network in a network site is responsible for the supply of DC power from the DC power source, usually located inside the shelter or cabinet at the bottom of the base station (BS) tower, to the radio units (RUs) deployed at the tower top.

DC power losses in current DC power distribution networks are rising over time, and thus, are a threat to network energy efficiency in the long-term. As illustrated in figure 11, which plots DC power losses as a function of the RU power consumption and the length of the DC power distribution network, if this industry continues building network sites using current DC distribution designs, an increase in DC power losses in the range of 4x to 10x can be expected, as more capable and power-hungry RUs are deployed. Furthermore, if the trend continues, the additional RUs, which will be deployed to support next generation networks, will further exacerbate the inefficiencies brought by these DC power losses.

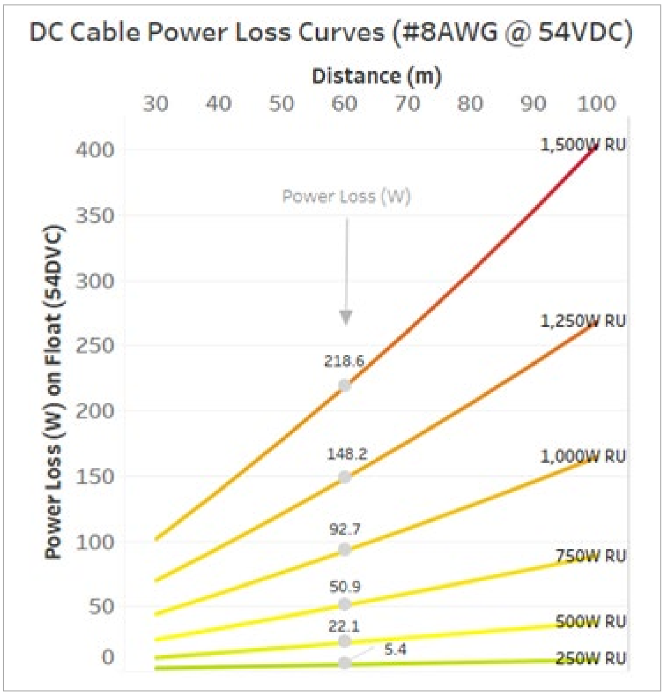

Figure 11: DC power losses calculated using two-way distances with typical #8 AWG DC trunk cables. Note the exponential relationship between the RU power consumption and the DC power losses due to the I2R law (i.e. for the same conductor size, the doubling of the DC current results in the quadrupling of the DC power losses)

Given the major upgrades that are currently taking place in network sites due to the deployment of 5G technology, mobile network operators (MNOs) have a unique opportunity to upgrade the DC power distribution networks of their network sites at the same time.
Our studies show that DC power distribution network efficiency can be notably enhanced by using simple structural approaches, some of which will be presented in the rest of this section. Advancements in DC power distribution can:

- significantly decrease DC power losses in the DC power distribution network,

- mitigate the need for 'DC Boosters' – thus further reducing power conversion losses, DC distribution complexity, and capital cost, and

- result in a new DC power distribution network standard, which can be used in all new network sites, and thus harvest further gains through economies of scale.

3.2.1 CURRENT DC POWER DISTRIBUTION NETWORKS

For a better understanding of the challenges around current DC power distribution networks, one should first understand the evolution of network sites over the past three decades:

Up until 2008, 1G and 2G networks typically had the RF amplifiers deployed inside the shelter or cabinet at the base of the BS tower – with large coaxial cables used to bring the radio frequency (RF) signals to the antenna at the top of the tower;

As the network evolved to 3G technology (approx. in 2008), the remote radio unit (RRU) concept was introduced, and as a result, RF amplifiers were located closer to the antenna, requiring DC power feeds from the cabinet at the base of the tower to the RRU location;

Based on the RRU power consumption requirements and forecasts at the time, most MNOs provided DC power to each RRU using a #8AWG-sized multiple conductor trunk cable power feed;

As a result of this common practice, running #8AWG multi-conductor DC trunk cables up the tower became the standard method to power RRUs in network sites across the world, and this continues to be the de facto standard today.

With this modus operandi, as more RRUs – and eventually AAUs – were deployed in network sites to make use of new spectrum bands and handle the larger data volumes encountered in 4G and 5G networks, an increasing number of #8AWG multi-conductor DC trunk cables had to be installed – on demand – over the tower, raising questions on the efficiency of this ad-hoc architecture (see figure 12). Importantly, it should also be noted that the use of advance networking solutions, e.g. massive MIMO, to deliver an enhanced user experience has significantly increased RU power consumption throughout the years – and especially in 5G. This increased RU power consumption, arising from the use of wider channel bandwidths, larger transmit power, increased carrier aggregation abilities, higher-order MIMO modes, and active beamforming, among other techniques, is further contributing to exacerbate the inefficiencies of this ad-hoc approach to distribute DC power in the tower.

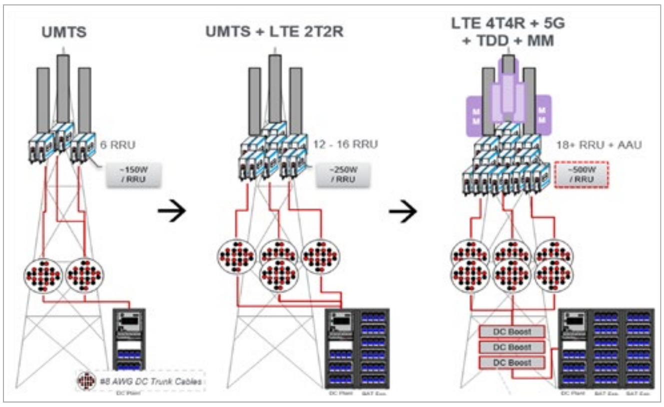

Figure 12: Evolution of DC power distribution network at network sites (2009 to present)

3.2.2 AN ENERGY EFFICIENT BULK FEED DC BUS ARCHITECTURE

Although there are various solutions that could help reducing DC power losses in network sites[4], there is one, which seems particularly appealing, due to its performance-complexity trade-off. This solution draws its inspiration from the widely used DC power bus system design often used in central offices [13]. Using a bus-based design, the inefficiencies of current solutions, in which individual power feeds for each RU are run from the base to the top of the BS tower can be avoided (Figure 13). In essence, this new bulk feed DC bus-based architecture uses (i) a bulk feed DC bus to bring DC power as close as possible to the RUs in the tower, and (ii) a tower top DC distribution box to supply energy from the bus to each one of the RUs. The solution should be designed so as to place the DC distribution box as close as possible to the RUs to benefit from the efficiency of the bus (Figure 14). To facilitate control, the DC power distribution box at the tower top can be remotely controlled through common interfaces and protocols such as TCP/IP or Modbus RTU. A remote control capability for the breakers at the top of the tower benefits operational teams, and opens up the possibility for much more effective shedding strategies during emergency outages[5]. Furthermore, if aluminium is used as material for the DC bus feeds in the new design[6], the cable material costs as well as the weight loading in the tower can be significantly reduced.

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[4] In this white paper, we only present what we consider to be the simplest and most cost effective solution for the most common scenarios. However, other solutions exist, which may be suitable depending on the system load and site design. Each of these other solutions have their own set of challenges in terms of technical feasibility, cost, and complexity, not to mention future growth and ongoing operational cost considerations.

[5] A hard shutdown of RUs avoids power waste versus a soft shutdown of RUs via the RAN EMS.

[6] Aluminium is typically 1/3 cost and 1/2 weight vs. copper for the same ampacity rating.

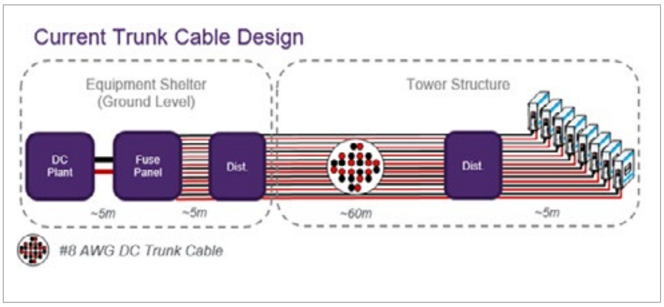


Figure 13: Current approach to DC power distribution network based on trunk cables. The figure shows a single sector with 8 RU's, where each RU is individually fed from the DC power source in the equipment shelter at the base of the tower

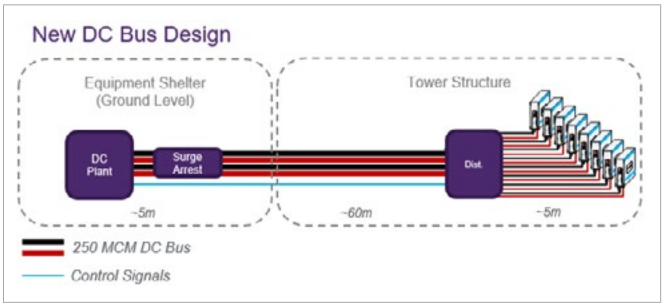


Figure 14: Bulk feed DC bus-based distribution network. The figure shows a single sector with 8 RUs. The bus transports the energy from the DC power source to the DC distribution network at the top of the tower. Redundant DC bus feeds (A + B configuration) branch off to power each RRU

3.2.3 ENERGY SAVINGS POSSIBLE THROUGH DC POWER LOSS REDUCTIONS

Power loss reductions per RRU of up to 60% are possible by optimising the DC power distribution in cell sites.

To assess the DC power loss reductions achievable via the proposed bulk feed DC bus design, in the following, a practical study example is provided. The example is based on a single sector equipped with 8 RRUs. The distance between the DC power source and these RRUs is 60m, and the DC bus is comprised of a single cable containing 4 conductors of 250MCM aluminium (one pair of conductors for the A feed, and the other pair for the B feed). Using this study case, two DC power distribution designs are compared, i.e. a benchmark based on 8 AWG trunk cables and the proposed bulk feed DC bus solution using dual feed A/B.

The following calculations are used to derive the DC power loss per RRU:

Parameters		
Float Voltage	54.00	VDC
Battery LVD Voltage (BLVD)	42.00	VDC
RRU Lowest Operating Voltage	39.00	VDC
Distance to RRU	60	m
RRU's per sector	8	count
Peak RRU Power	1000	Watts
Average RRU Power (50%)	500	Watts
RRU Power Cable Size	8	AWG
Bulk Feed DC Bus Size (Dual Feed A/B)	250 MCM	AWG
Copper or Aluminum Bus?	Al	Conductor
Electricity Rate	0.13	$/kWh

Dual Feed Bus Design - OpEx Savings		
Measured Improvements	Peak	50%
Power Loss Reduction per RRU (%)	60%	60%
Power Loss Reduction per RRU (W)	59.67	14.92
Power Loss Reduction per RRU (kWh/yr)	523	131
Power Loss Reduction per RRU ($/yr)	$ 67.95	$ 16.99
Power Loss Reduction per Site ($/yr)	$ 1,630.87	$ 407.72

> 8AWG calcs based on standard 12C ShawFlex Trunk Cable

Single RRU Feed Design (Trunk Cables)		
Normal Operation (on Float)	Peeak	50%
I (A)	18.52	9.26
V (drop)	5.36	2.68
Power Loss per RRU (W)	99.18	24.79
Voltage at Load	48.64	51.32

Bulk Feed DC Bus Design (per Branch A/B)		
Normal Operation (on Float)	Peak	50%
I (A)	74.07	37.04
V (drop)	2.13	1.07
Power Loss per RRU (W)	39.51	9.88
Voltage at Load	51.87	52.93

Note that the following calculations are used to compute the proposed bulk feed DC bus design:

*I (A) = RRU Power (Watts) * # of RRU's per sector / Float Voltage (Volts) / 2*

Note that the total current draw is divided by 2 since a split A/B bus design is used (half of the RRU's are powered by each A/B branch – in the above example, there are 4 RRU's per branch).

*V (drop) = I(A) * Cable Resistance (Ohms/m) * Distance to RRU (m) * 2*

Note that the distance is multiplied by 2 to account for the full circuit resistance of the cable.

*Power Loss per RRU (W) = I(A) * V (drop) / # of RRU's in each branch*

Power Loss Reduction per RRU (%) = 1 - (Single RRU Feed Design Power Loss per RRU (W) / Bulk Feed DC Bus Design Power Loss per RRU (W))

3.2.4 DC POWER DISTRIBUTION OPTIMISATION – RECOMMENDATIONS

Overall, we see the need to update DC power distribution networks in those network sites where DC power feed cables have been deployed in an ad-hoc manner. Solutions like the discussed bulk feed DC bus design can bring advantages in terms of network energy efficiency.

Significantly, our theoretical calculations show that DC power losses can be reduced by up to 60%, as shown in the previous practical example. In addition, it should be noted that the complexity of the power design can be simplified at the base of the tower, when using more advanced DC power distribution networks, as DC boosters are no longer required, which in turn, also ties up less breaker positions in the power plant. We advocate for the use of aluminium for the bulk feed DC conductors, significantly lowering capital costs and weight loading on the tower structure.

3.3 POTENTIAL OF RENEWABLE ENERGY AT RAN SITES

Deploying renewable energy (solar, wind etc) at RAN sites, although not saving energy, does have a role to play in reducing operators' CO2 emissions and even energy bills and reducing their reliance on energy providers. Advances in battery and fuel cell technology combined with energy management solutions can also further improve the overall energy and environmental footprint of a mobile network. NGMN expects to track this developing area in future reports.

04 NEW TECHNOLOGIES FOR NETWORK ENERGY SAVING

Investing in new infrastructure and services offers wide-ranging potential for energy savings. In this chapter we highlight three key areas – cooling, network disaggregation, and radio/channel enhancements where new technologies are emerging that will help further raise the energy efficiency of mobile networks. By definition, although in many cases these technologies are becoming commercially available they are – in general – 'emerging' as in many cases they have not yet been adopted at scale and/or they require further definition and (where appropriate) standardisation. They should however be part of an operator's medium to long term planning regarding reducing energy consumption.

4.1 COOLING

Computing infrastructure used in mobile networks generate significant quantities of heat. As such, cooling systems have become a significant consumer of energy in networks accounting for up to 40% of RAN energy consumption [1], heavily depending on the site configuration and location (e.g. indoor/outdoor, climate, …) and 52% of energy consumption in data centres [14] [15]. Clearly reducing the energy consumed by cooling systems would have a large impact on overall network energy efficiency, especially interesting in equipment rooms or centralized BB sites.

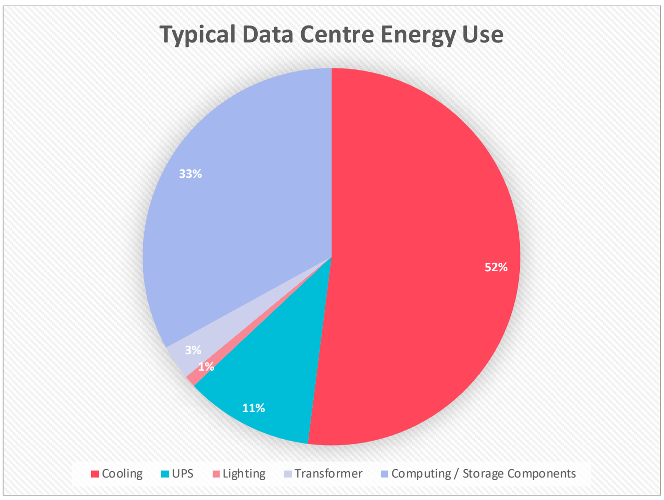


Figure 15: Data Centre Energy Use

4.1.1 NEW COOLING TECHNOLOGIES

Traditionally air-cooling has been used to cool computing infrastructure. New technologies – based on using dielectric liquids instead of air as the coolant – are emerging that promise to substantially reduce the energy required for cooling. There are two major forms of cooling – liquid immersion cooling and direct contact liquid cooling (DCLC). In both cases, although the technology is being piloted and deployed in some RAN Baseband units or in IT data centres, it is not yet mainstream in terms of deployment at scale in mobile networks. To fully benefit from liquid cooling techniques requires also that telecoms equipment is adapted (to e.g. remove moving parts such as fans and hard disks, and interconnect the liquid cooling solution to heat exchanger or heat re-use systems).

4.1.1.1 LIQUID IMMERSION COOLING

Liquid immersion cooling is an advanced form of cooling in IT, in which the equipment to be cooled, for instance, a server, is completely immersed in a thermally conductive dielectric liquid [16].

Since the thermal conductivity of a fluid is orders of magnitude larger than that of air due to is higher concentration of particles, liquid immersion cooling is a more efficient approach than air-cooling. Because the entire equipment – and not only a few components – are in contact with liquid, liquid immersion cooling leads to lower PUEs (i.e. increased energy efficiency) than its major alternative - Direct Contact Liquid Cooling (DCLC).

There are two major forms of liquid immersion cooling – single phase and two phase. In single phase the cooling liquid has a high boiling temperature and thus never changes state. The liquid is passed around the data centre racks and heat is exchanged via a heat exchanger. In the two-phase approach the cooling liquid changes phase from liquid to gas, keeping the temperature of the dielectric liquid at – or just below – its boiling temperature. The cooling liquid must thus have a boiling temperature that is adequate to cool the equipment under consideration, typically around 50 degrees Celsius. A condenser is further used to convert the generated gas into liquid again. Generally speaking, due to evaporation from liquid to gas, the two-phase cooling can provide better energy efficiencies than the single-phase one.

4.1.1.2 DIRECT CONTACT LIQUID COOLING

Direct Contact Liquid Cooling (DCLC) as its name implies is a form of liquid cooling where only certain components are liquid cooled (rather than the entire infrastructure). In general, because DCLC cooling only liquid cools specific components the overall energy savings that can be achieved are lower than for liquid immersion cooling – i.e. the PUE for data centres that use DCLC would be higher than those using liquid immersion cooling. However DCLC may be a nearer term solution to liquid cooling as it is likely easier to migrate specific energy intensive components (CPUs, GPUs, accelerators etc) to liquid cooling than to migrate entire racks and data centres containing infrastructure from multiple vendors.

4.1.2 LIQUID COOLING ENERGY SAVINGS AND CO2 REDUCTIONS

Liquid immersion cooling is already in use in some edge nodes and data centres, and thus inferences can be made about its performance.

For reference, the average PUE of a legacy air-cooled cloud service provider data centre is between 1.3 to 2, based on factors like external climate, ambient operating temperature, power delivery network availability ratio, uninterruptible power supply/battery backup and IT capacity loading. For example, Orange's data centre, Normandie, located in the northwest of France, has a PUE of 1.3.

Immersion cooling has been shown to be able to push down the PUE to 1.02 in similar data centre scenarios, if all IT equipment is immersed in the fluid. By contrast, a typical cloud service provider data centre based on a mix of immersed (e.g., compute/ communication) and non-immersed (e.g. HDD storage, network switches) IT hardware can achieve a PUE between 1.02 [17] and 1.1, still significantly outperforming air-cooling [18] [19] [20].

Research has also shown that liquid immersion cooling with energy reuse (e.g. district heating) could reduce carbon emissions by 45% compared to traditional data centre usage [21] [22].

4.2 NETWORK DISAGGREGATION

Network Disaggregation – whereby network functions are instantiated in software running on computing infrastructure(s) – could offer benefits in terms of energy efficiency but may also be less energy efficient in the short term. In general, network disaggregation – in all domains – RAN, Core Network, Transport – is a clear trend within the industry. It is therefore very important to fully consider the environmental impact of network disaggregation and how to ensure it is energy efficient. In this section we highlight how network disaggregation may help improve network energy efficiency and we outline the key next steps to determining the energy consumption of disaggregated networks and therefore how the energy savings offered by network disaggregation may be calculated.

4.2.1 ENERGY SAVING POTENTIAL

The softwarisation of the network and the reliance on a (cloud) compute infrastructure to host network functions (whether via virtualisation or cloud-native approaches) has great potential to enable energy savings through more efficient operations. The energy saving potential stems from the flexibility and scalability that is an inherent feature of disaggregated networks. For example, deploying disaggregated networks supported by suitable network management automation should enable the supply (of network functions to offer the service) to be more closely matched to demand. Similarly, operators could derive further benefits from network disaggregation through the ability to move compute loads to data centres that have access to renewable energy (and away from places that have less renewable energy due to e.g. lack of sunshine or wind).

However, there are a number of (near-term) challenges to network disaggregation's ability to make networks more energy efficient. These challenges include that disaggregation itself involves taking network function(s) that were previously highly integrated (custom software / custom hardware) and thus highly efficient and moving towards deploying network function(s) that must work in more general-purpose computing environments (and may be less energy efficient). An additional challenge is the need for determining what resources (in the underlying compute infrastructure) are used by the network functions and how the energy consumption of those resources can be accurately measured and reported to the operator's network management. NGMN expects to track this developing area in future reports.

4.3 ADVANCED RADIO TECHNOLOGIES

The radio channel (modulation used, coverage required, environment, and geography) has a substantial impact on the power needed to offer sufficient coverage, capacity, and service to users. Radio technologies that are more efficient at transmitting information to users will help to improve overall network energy efficiency. Two examples of technologies currently under study by the industry are: Reconfigurable Intelligent Surfaces (RIS) and using Distributed Multiple Input Multiple Output (DMIMO) transmission.

4.3.1 RECONFIGURABLE INTELLIGENT SURFACES

A reconfigurable intelligent surface (RIS) is comprised of a passive two-dimensional array, built of a large number of reconfigurable electromagnetic elements, and a control logic. By intelligently tuning these reconfigurable electromagnetic elements, through the control logic, the properties of the electromagnetic waves reflected by the RIS, e.g. amplitude, phase and polarization, can be dynamically changed [25]. Equipped with this capability, RIS deployments, in walls and ceilings indoors, and in buildings or signage outdoors, provide mobile network operators the means to influence/'tune' – up to a given extent – the behaviour of the wireless channel.

4.3.1.1 ENERGY SAVING POTENTIAL OF RIS

The energy saving potential of RIS is shown in figure 16. To arrive at this figure field tests were conducted using a baseline system and a RIS-assisted system.[7] In both systems the radio technology used was 5G-NR (various frequencies and scenarios – see table 4). The field tests measured the average signal power received (RSRP) and the downlink throughput. Based on these measurements (see table 4), system-level simulations were then conducted to understand the impact on power consumption of each system. The results of the simulation (shown in figure 16) highlight that at higher spectral efficiencies (> 5 bits / second / Hz) the energy efficiency of an optimally dimensioned RIS-assisted system is larger than that of baseline system under the same conditions. Indeed, optimally dimensioned RIS-assisted systems may be able to offer network energy efficiency gains of up to 3.5 times that of baseline (non-RIS assisted) systems.

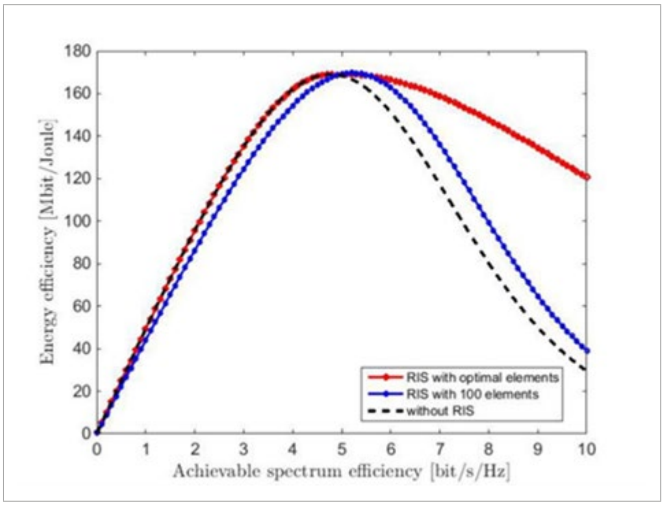
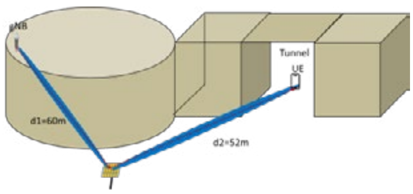
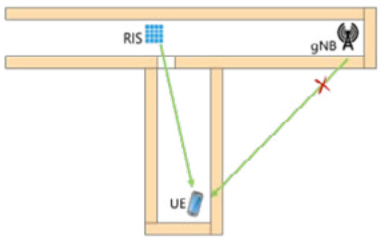


Figure 16: Energy Efficiency of 5G-NR RIS assisted v 5G-NR Baseline system

[7] Field tests and simulations were conducted by ZTE. The energy saving figures reported for RIS are the numbers reported by ZTE in their presentations to NGMN.

<table>
<tr><th>Scenario</th><th>Set Up</th><th>Field Test Results</th></tr>
<tr><td rowspan="5">Outdoor to indoor</td><td>
</td><td rowspan="5">Up to 21dB RSRP improvement with the assistance of RIS (codebook approach)

Up to 4.4x downlink throughput improvement</td></tr>
<tr><td>4.9 GHz gNB</td></tr>
<tr><td>Bandwidth: 100MHz</td></tr>
<tr><td>RIS elements: 32 x 32 (equally spaced)</td></tr>
<tr><td>Size of the RIS: 1m x 1m</td></tr>
<tr><td rowspan="6">Outdoor</td><td>
</td><td rowspan="6">Up to 10dB RSRP improvement with the assistance of RIS

Up to 40% downlink throughput improvement</td></tr>
<tr><td>C-band 3.5 GHz gNB</td></tr>
<tr><td>Bandwidth: 80MHz</td></tr>
<tr><td>Link between BS and RIS: line of sight (LOS), distance 60m</td></tr>
<tr><td>Link between RIS and UE: non line of sight (NLOS), distance 52m</td></tr>
<tr><td>Size of the RIS: 40cm x 40cm</td></tr>
<tr><td>Indoor</td><td>
</td><td>Up to 35dB RSRP improvement with the assistance of RIS</td></tr>
<tr><td></td><td>High frequency scenario (i.e. mmWave)</td><td></td></tr>
<tr><td></td><td>The link between the BS and UE is blocked by the building wall</td><td></td></tr>
</table>

4.3.2 DISTRIBUTED MIMO

Distributed MIMO (DMIMO) is a form of massive MIMO transmission technology that is being considered for 6G [26]. In DMIMO all – or at least a large number of transmission and reception points (TRPs) – in a wide coverage area co-operate and jointly serve all surrounding user equipment (UE) using the same time or frequency resources. The DMIMO TRPs operate as a distributed massive MIMO array coordinated by a central processing unit (CPU) through a fronthaul network. The most ambitious form of DMIMO is cell-free massive MIMO [27]. DMIMO removes traditional cell boundaries, and significantly mitigates inter-cell interference. Compared to conventional co-located massive MIMO, DMIMO networks offer more uniform connectivity to UEs given the macro-diversity gain provided by the distributed antennas.

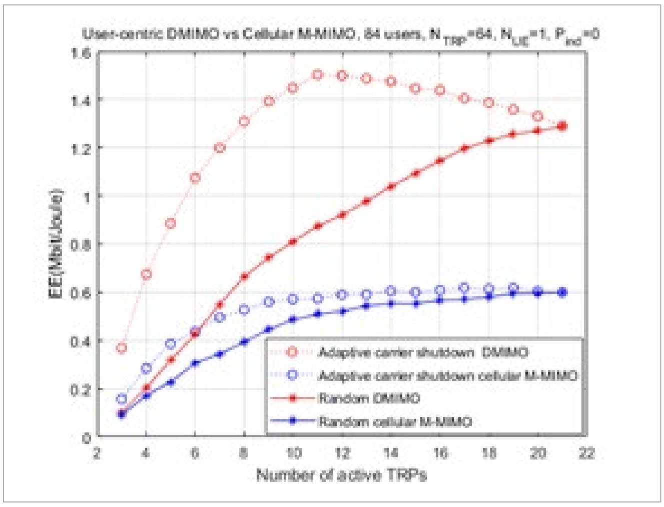


Figure 17: Distributed (cell-free) massive MIMO vs cellular massive MIMO energy efficiency with adaptive sleep modes for 84 Ues

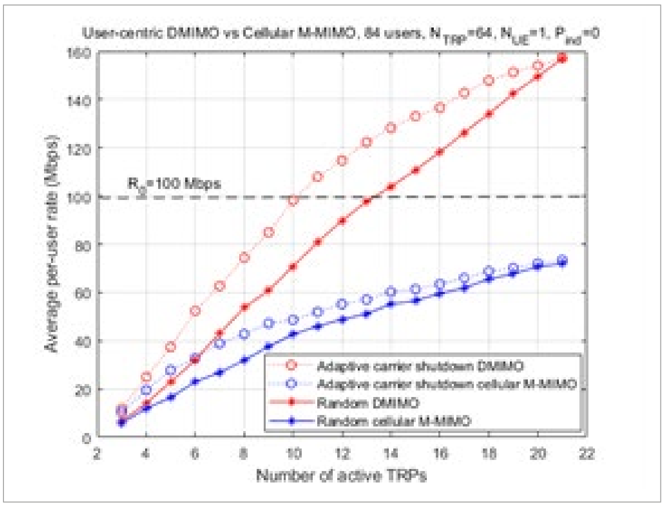


Figure 18: Distributed (cell-free) massive MIMO vs cellular massive MIMO average per-UE rate with adaptive carrier shutdown for 84 Ues

4.3.2.1 ENERGY SAVING POTENTIAL OF DMIMO

To assess the potential network performance and energy efficiency gains of an outdoor, macro base station (BS)-based DMIMO architecture, system-level simulations with an environment (dense urban-enhanced mobile broadband) as described in [28] were used. The results of these simulations are depicted in figures 17 and 18 which show respectively the network energy efficiency (Mbits / joule) and the average per user bit rate for both DMIMO and (traditional) cellular massive MIMO. In the simulations, each system was configured and simulated for varying number of TRPs to serve the 84 users half of which were concentrated around two separate hotspots with the other UEs being uniformly distributed.

It is clear from the simulation data that DMIMO combined with adaptive carrier shutdown could offer substantial benefits (up to 2.5 times more energy efficient than cellular MIMO) in terms of network energy efficiency whilst at the same time being able to offer average per-user throughput rates that cannot be matched by cellular MIMO.

05 RECOMMENDATIONS

NGMN recommends that operators review the energy saving potential of each option offered in this publication and that further studies are conducted regarding the energy saving potential of key technologies such as ML, network disaggregation and cloudification. Additionally, studies should be undertaken to review the state of the art in energy management and renewable energy solutions to provide further timely guidance to the industry.

Table 3 provides examples of energy saving potential from technologies described in this report.

Table 3: Examples of Energy Saving Potential and timeframes of various energy saving methods

Area	Energy Saving Solution	Examples of Energy Saving Potential	Timeframe
Process Optimisation	Rules-based automation (of 3GPP energy saving features) (Sec. 2.1.3.1)	3% energy reduction in a 4G/5G network	Short term
	AI based automation (of 3GPP energy saving features) (Sec. 2.1.3.2)	9% energy reduction in a 4G/5G network	Short term
Engineering Optimisation	Replace single band RRUs with tri-band remote radio units (RRUs) using multi-band Power Amplifiers (Sec. 3.1.1.1)	30% energy saving per RRU	Medium term
	Increase 'antenna gain' by doubling antenna elements per Power Amplifier in the vertical direction (Sec. 3.1.1.1)	Up to 30% energy saving per active antenna unit (AAU)	Medium term
	Passive Antennas: Simplify RF feeding paths (Sec. 3.1.3.1)	Up to 50% reduction in feeding path losses for a typical passive antenna configuration	Medium term
	Reduce DC power losses in cell sites by moving to bus based architectures (Sec 3.2)	60% reduction in DC power losses per RRU	Medium term
New Technologies	Direct Contact Liquid Cooling (DCLC) (Sec. 4.1.1.2)	Lower energy saving than for liquid immersion cooling but easier to migrate RAN baseband cards or IT equipment to liquid cooling than to immerge entire racks	Medium term
	Liquid Immersion Cooling (Sec. 4.1.1.1)	Can reduce the Power Usage Effectiveness (PUE) of a data centre to 1.02 (compared to PUE= 1.3 to 2 for air cooled)	Long term

Area	Energy Saving Solution	Examples of Energy Saving Potential	Timeframe
New Technologies	Network Disaggregation and cloudification (closely matching network supply to demand) (Sec. 4.2)	Further study needed	Long term
	Reconfigurable Intelligent Surfaces (RIS) (Sec. 4.3.1)	Network Energy Efficiency up to 3.5 times greater than baseline (non-RIS assisted) networks	Late 5G Advanced / Long term
	Distributed (cell-free) Massive MIMO (DMIMO) (Sec. 4.3.2)	Network Energy Efficiency up to 2.5 times greater than cellular massive MIMO	Long term

06 ABBREVIATIONS

5G-NR	5G New Radio
AAU	Active Antenna Unit
AI	Artificial Intelligence
API	Application Programming Interface
AWG	American Wire Gauge
BBU	Baseband Unit
BU	Baseband Unit
CNF	Cloud native network function
CO2	Carbon Dioxide
CU	Central Unit
DC	Direct Current
DCLC	Direct Contact Liquid Cooling
DL	Downlink
DMIMO	Distributed Massive MIMO
FDD	Frequency Division Duplex
IP	Internet Protocol
KPI	Key Performance Indicator
kWh	kilowatt hour
LTE	Long Term Evolution
MIMO	Multiple Input Multiple Output
ML	Machine Learning
NFV	Network Function Virtualisation
PA	Power Amplifier
PRB	Physical Resource Block
PUE	Power Usage Effectiveness
RAN	Radio Access Network
RIS	Reconfigurable Intelligent Surface
RRU	Remote Radio Unit
RSRP	Reference Signal Receive Power
RU	Radio Unit
TCP	Transmission Control Protocol
TDD	Time Division Duplex
UE	User Equipment (the 'mobile phone')
VNF	Virtual Network Function

07 ACKNOWLEDGEMENTS

NGMN would like to thank the following people who made significant contributions to the development of this publication:

Aleksis Anterow, Huawei Technologies
Saima Ansari, DT
Javan Erfanian, Bell Canada
Derek Arsenault, Telus
Martin Bakhuizen, Huawei Technologies
John Browne, Intel
Sébastien Chainon, RFS World
Rishikesh Chakraborty, Vodafone
Jiajun Chen, ZTE
Xin Chen, Huawei Technologies
Sanghoon Cho, SK Telecom
Chris Mac Namara, Intel
Jean Michel Cornily, Huawei Technologies
Jacob Chenjun, Huawei Technologies
Pierre-Yves Descombes, HPE
Daniel Dianat, Ericsson
Antonio De Domenico, Huawei Technologies
Norbert Entstrasser, DT
Xinli Geng, Huawei Technologies
Ljupco Jorguseski, TNO
Daniela Laselva, Nokia
Mads Lauridsen, Nokia
Gary Li, Intel
Jianhua Liu, China Mobile
David Lopez-Perez, formerly Huawei Technologies
David Nortershauser, Orange
Magnus Olsson, Huawei Technologies
Paul Pfundt, DT
Dinh-Thuy Phan-Huy, Orange
Nicola Piovesan, Huawei Technologies
Philippe Ratajczak, Orange
William Redmond, Intel
Carlos Tomas Rodriguez, Orange
Juan Serrano, Orange
Manish Sharma, Intel
Sonja Schmitt, DT
Hitesh Srivastava, Intel
Pedro Torres, CommScope
Lee Valerius, HPE
Nanbin Wang, Huawei Technologies
Shuang Zheng, ZTE
Junghee Son, SK Telecom

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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