5G and
Energy Efficiency

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Introduction

From the introduction of "1G" over 30 years ago, to today with the widely-used "4G" and the debut of "5G", a lot has changed and notably in the way people work, live and play. Figure 1 gives an overview of the shifts and changes across the various telecommunication generations.

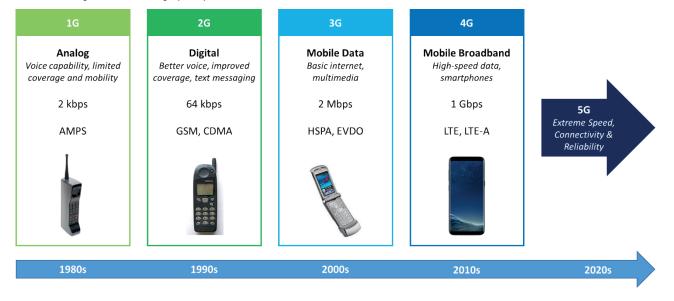| 1G	2G	3G	4G	
Analog	**Digital**	**Mobile Data**	**Mobile Broadband**	
Voice capability, limited coverage and mobility	*Better voice, improved coverage, text messaging*	*Basic internet, multimedia*	*High-speed data, smartphones*	**5G**
2 kbps	64 kbps	2 Mbps	1 Gbps	*Extreme Speed, Connectivity & Reliability*
AMPS	GSM, CDMA	HSPA, EVDO	LTE, LTE-A	
1980s	1990s	2000s	2010s	2020s

Figure 1: Evolution in cellular technology from 1G to 5G (Source: 5GAmericas)

After 4G, a new generation is about to arrive: 5G, the fifth telecommunication generation. 5G should allow:

› 1000 times more data transmission capacity

› 10 to 100 times more connected objects

› 5 times more responsiveness

› 90% energy savings

› Everywhere the same efficiency[1]

The ambition of the 5G is to increase usage, speed and services of telecommunication whilst reducing energy consumption. This aspect regarding energy efficiency is particularly important in today's environment, in which the planet has to face climate change, energy and material waste, pollution and many other issues.

This document describes the 5G performance requirements in a first section. Environmental issues due to 5G implementation are treated in a second section. A third section explains the legacy specifications for 5G in mobile networks in Europe. Finally, a fourth section provides, by means of a literature review, an analysis of the main solutions currently proposed to increase 5G energy efficiency.

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1   5G PPP Video: https://youtu.be/bfNmiYtG9Cg.

1. 5G performance requirements

I n order to differentiate 5G from 4G and to standardize 5G, overall requirements have been listed by the ITU. The KPIs for 5G wireless technology at the ITU level are grouped into the three following categories:

› eMBB: enhanced mobile broadband

› URLLC: ultra-reliable and low-latency communications

› mMTC: massive machine type communications

The following table summarizes the main 13 KPIs[2]:

5G performance requirement type	Minimum KPI requirement	Category
Peak Data rate	Downlink (DL) peak data rate: 20 Gbit/s Uplink (UL) peak data rate: 10 Gbit/s	eMBB
Peak Spectral Efficiency	Downlink peak spectral efficiency: 30 bits/s/Hz Uplink: 15 bits/sec/Hz	eMBB
User experienced data rate	Downlink user experienced data rate: 100 Mbit/s Uplink user experienced data rate: 50 Mbit/s	eMBB
Average spectral efficiency	Indoor hotspot: › DL: 9 bit/s/Hz/TRxP › UL: 6.75 bit/s/Hz/TRxP Dense Urban: › DL: 7.8 bit/s/Hz/TRxP › UL: 5.4 bit/s/Hz/TRxP Rural: › DL: 3.3 bit/s/Hz/TRxP › UL: 1.6 bit/s/Hz/TRxP	eMBB
Area traffic capacity	Downlink: 10 Mbit/s/m² in the indoor hotspot – eMBB test environment	eMBB
User plane latency	4 ms for eMBB 1 ms for URLLC	eMBB and URLLC
Control plane latency	20 ms (10 ms encouraged)	eMBB and URLLC
Connection density	1 million devices per km²	mMTC
Energy efficiency	a) Efficient data transmission in a loaded case: demonstrated by the average spectral efficiency b) Low energy consumption when there is no data: should support a high sleep ratio and long sleep duration	eMBB

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2   https://5g-ppp.eu/wp-content/uploads/2017/10/Euro-5G-D2.6_Final-report-on-programme-progress-and-KPIs.pdf.

5G performance requirement type	Minimum KPI requirement	Category
Reliability	1-10^{-5} success probability of transmitting a layer 2 PDU of 32 bytes within 1 ms in channel quality of coverage edge for Urban Macro-URLLC test environment, assuming small application data	URLLC
Mobility	Indoor hotspot: stationary, pedestrian* Dense urban: stationary, pedestrian, vehicular (up to 30 km/h) * Rural: pedestrian, vehicular, high speed vehicular (up to 500 km/h)* *Traffic channel link data rates normalized by bandwidth are also defined but not included here*	eMBB
Mobility interruption time	0 ms	eMBB and URLLC
Bandwidth (maximum aggregated system)	At least 100 MHz Up to 1 GHz for operation in higher frequency bands (e.g. above 6 GHz)	IMT-2020

2. Environmental issues due to 5G

Today, the Information and Communication Technology (ICT) industry represents an important energy consumer and environment polluter. Indeed[3]:

› ICT uses approximately 4% of the world's electricity today and is expected to reach 10% to 20% of the world's electricity consumption in 20304

› The ICT industry has the same carbon footprint as the aviation industry

› The exponential growth of data will drive energy consumption

The fifth telecommunication generation represents an evolution of current systems but also a revolution to satisfy the new needs of the innovative services offered by the "vertical" areas in the telecommunication environment. These verticals include smart homes/buildings, smart cities, augmented reality, industrial automation, health, etc. The main idea behind 5G is to minimize total network energy consumption, despite increased traffic and service expansion due to its use for these verticals and the general increase in data consumption by worldwide users.

To fully deploy 5G, a dense infrastructure for base stations and small cells has to be implemented as illustrated in Figure 2.
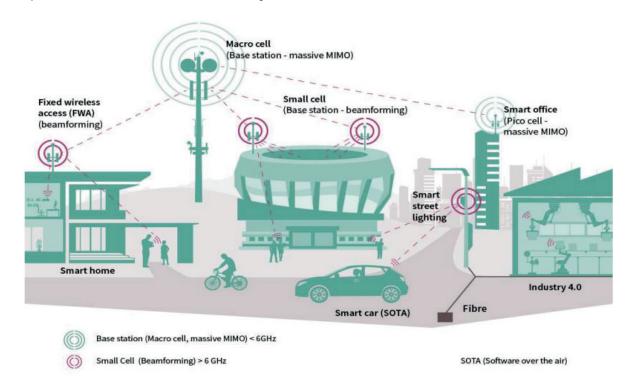

Figure 2: 5G Infrastructures (Source ETSI EE/EE2 power)

The following aspects of 5G deployment are the main drivers expected to lead to higher energy consumption (up to 1000 times as much energy[5]):

› A denser base station infrastructure than in today's infrastructure: from 4/8 antennas to 64/128 antennas

3   GAPWAVES AB (2017) Antenna Technology for 5G.
4   https://www.enerdata.net/publications/executive-briefing/expected-world-energy-consumption-increase-from-digitalization.html.
5   Dexter Johnson (2018) *The 5G Dilemma: More Base Stations, More Antennas – Less Energy?*

› The use of denser networks: from a homogeneous network with 1-3 BSs/ 1km² towards HetNets with 10-100 nodes/ 1km²

› The use of higher frequencies: from 100 MHz up to 5 GHz

› The need for larger amounts of storage6.

Therefore, energy efficiency and methods to reduce energy consumption have become a hot topic in today's conferences and literature.

6   https://docbox.etsi.org/Workshop/2017/20171123_ITU_ETSI_ENV_REQ_5G/S01_PART1/POWERING_5G_ETSIEE_ITUTSG5_MARQUET.pdf.

3. Legacy specifications for Energy Efficiency in mobile networks

Several organisations have been working on setting a path for 5G research for the past several years. The International Telecommunication Union (ITU) and the 3GPP (3rd Generation Partnership Project) have started setting standards for the success of 5G.

A. The International Telecommunication Union

As early as 2012, the International Telecommunication Union (ITU) set the stage for 5G research activities through a programme called "IMT for 2020 and beyond", and has finalized its "Vision" of the 5G mobile broadband connected society since 2015[7]. Notably, two frameworks were established by the ITU:

1. ITU-R IMT M2083 Vision:

In this document, it is stipulated that: "*The energy consumption for the radio access network of IMT-2020 should not be greater than IMT networks deployed today, while delivering the enhanced capabilities. The network energy efficiency should therefore be improved by a factor at least as great as the envisaged traffic capacity increase of IMT-2020 relative to IMT-Advanced for enhanced Mobile Broadband*"[8].

2. ITU-R IMT-2020. Tech perf req Perf Req:

This document explains that: "*It is required that the 5G mobile networks have the capability to support a high sleep ratio and long sleep duration and other energy saving mechanisms for both network and device are encouraged*"[9].

B. The 3rd Generation Partnership Project (3GPP)

The 3GPP has also started setting standards for the success of 5G, notably the following:

1. RAN: TR 38.913 "Study on scenarios and requirements for Next Generation Access Technologies"

In this study is stated that "Network energy efficiency shall be considered as a basic principle in the NR design" and in which qualitative inspection is suggested, for energy efficiency and quantitative analysis.

2. SA: TR 21.866 "Study on Energy Efficiency Aspects of 3GPP standards"

This study defines the KPIs related to Energy Efficiency. These KPIs include measurements of both Energy Consumption (EC) and Energy Efficiency (EE). EC and EE are measured at RAN and system-wide level including during a predefined time interval.

7   https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Pages/default.aspx.
8   https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf.
9   https://www.itu.int/md/r15-sg05-c-0040/en.

The EE per deployment scenario with a load level of 1 is defined as[10]:

$$EE_{scenario\ i} = \sum_{load\ level\ l} a_l \frac{V_l}{EC_l}$$

EE *scenario*: sum of traffic load points over the EC weighted by a_i in consideration of the traffic load per scenario.

V1 (in Mbps): aggregated throughput served in the simulated or measured area for traffic level 1, or equivalently served traffic volume divided by the simulation or measurement period.

EC1 (in Watt): sum of the average power consumption of all nodes in the simulated or the measurement area under the load level 1.

The total energy efficiency for the whole system including all the targeted scenarios is defined as[11]:

$$EE_{global} = \sum_{scenario\ i} b_i EE_{scenario}$$

EE *global*: sum of the EE scenarios per deployment scenario multiplied by the corresponding weight, b_i, for each deployment scenario.

b_i: determined by summing the "rural/suburban" weights for the coverage-limited scenario and the "urban/dense urban" weights for the capacity-limited scenario.

3. SA: WI on FS_EE_5G "Study on system and functional aspects of Energy Efficiency in 5G networks"

This study gives KPIs to measure the EE of base stations in static and dynamic mode, and explains the measurement methods to be used based on the ETSO TC EE and ITU-T SG5 works.

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10 3GPP (2017) 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Study on Energy Efficiency Aspects of 3GPP Standards (Release 14).
11 3GPP (2017) 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Study on Energy Efficiency Aspects of 3GPP Standards (Release 14).

4. How to improve 5G energy efficiency according to the literature?

The energy efficiency of 5G has received significant attention in the literature. This section reports on the major findings concerning solutions for increasing the energy efficiency of 5G.

Emil Björnson, an associate professor at Linköping University in Sweden, has devoted a portion of his current research to addressing 5G energy efficiency[12]. For him, two fundamental aspects of 5G are an increase in the number of small cells and the rise of massive multiple-input multiple-output (MIMO) antennas. The increased number of small cells will logically imply higher energy consumption, but it has been pointed out that the individual energy consumption of each small cell is much lower than in a conventional cell. Concerning massive MIMO, it involves the use of arrays with many more antennas at each base station, which requires many more hardware components per base station and therefore more energy. Nevertheless, according to Emil Björnson, there are solutions available to increase 5G energy efficiency:

› As massive MIMO technology develops, its energy efficiency may also improve over time. Indeed, the MAMMOET project has predicted that future massive MIMO base stations will consume less energy than 4G base stations, despite the fact that they will contain more hardware.

› Due to the spatial multiplexing capacity (serve many more users at the same time and frequency) of massive MIMO hardware, the energy consumption is divided up between users.

› The possibility to put the base stations in "sleep mode" when there are no active users is one of the main ways to reduce energy consumption. Indeed, it is expected to reduce

energy consumption by almost 10 times compared to current systems.

This last solution concerning the "sleep mode" of the base station has been identified in multiple research studies as one of the key elements enabling a reduction in energy consumption. In the study "On the road to Energy Efficient 5G Mobile Networks" of Zoran Bojkovic, Miodrag Bakmaz and Bojan Bakmaz[13], the idea of a "sleep mode" is also highlighted in order for the infrastructures to be energy-efficient. Indeed, according to this study those 5G systems with high energy consumption should always be built on the principle of only being active and transmitting when and where needed.

According to the white paper released by Nokia on "5G network energy efficiency"[14], attention should be focused on the base stations, as they consume 80% of the energy used (only 15% of the energy is used to forward bits). Most of the energy is used for system broadcasts and running idle resources, to power fans and cooling systems (over 50% of the energy consumption), for heating and lighting, and to run uninterruptible and other power supplies. There should be a focus on these aspects to reduce energy consumption. Nokia has identified several major opportunities to reduce the energy consumption of the base stations:

› Reduce energy consumption when the base station has no data to be sent – "sleep mode"

› Reduce energy consumption due to auxiliary equipment (like cooling systems)

› Increase hardware efficiency, particularly when operating below maximum power

As illustrated in Figure 3, the share of traffic and the share of base stations is not proportional when it comes to traffic distribution over the network. Indeed, 80% of the traffic is in general

12 https://spectrum.ieee.org/energywise/telecom/wireless/will-increased-energy-consumption-be-the-achilles-heel-of-5g-networks.

13   https://pdfs.semanticscholar.org/ef60/1485b87056722da6a7bd3d4f6a4d2d6101b1.pdf.

14   https://onestore.nokia.com/asset/200876.

carried by 30% of the base stations, and the remaining 70% of base stations only carry 20% of the traffic and their utilization is low. The main reason for this is the unequal traffic distribution due to coverage requirements: networks need to provide coverage in those areas where traffic density is low. Energy efficiency could be particularly improved in those low-load areas[15].
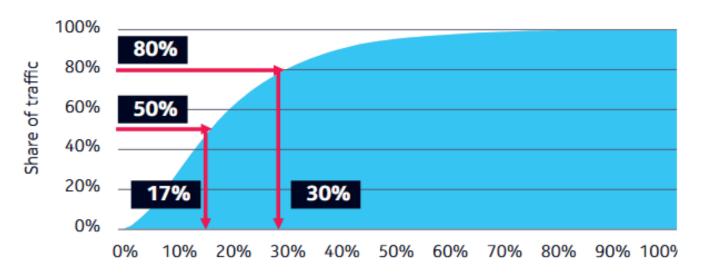

Figure 3: Traffic distribution over the network (Source: Nokia White Paper)

Figure 4 illustrates the traffic distribution over a 24-hour period. As shown in the figure, a busy hour carries 60-70% more traffic than an average hour and substantially more traffic than low- traffic hours during the night. Therefore, there is an opportunity to improve the network's energy efficiency during the low-load periods.
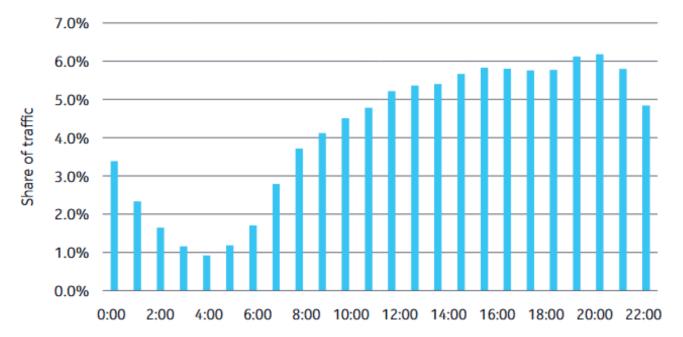

Figure 4: Traffic distribution over 24h period (Source: Nokia White Paper)

Concerning sleep mode, today in LTE radios the duration of the sleep mode is limited due to the reference signals which need to be transmitted four times in every 1 ms period. The flexible reference signal design in 5G, will allow to make better use of the sleep mode and consequently

15 https://onestore.nokia.com/asset/200876.

allow more energy savings. It is even expected that the potential reduction in power consumption with these features ranges from 30% to 70% compared to LTE. Moreover, since the small cells cover only limited areas, it is likely that there are no users in some of the small cells at certain times outside the busy hours. To switch off unused small cells will be an option to reduce energy consumption. Another option is to switch off some of the small cells when the traffic is low, and to have only a few small cells take over the traffic when the geographic coverage allows it[16].

In a presentation on "5G and Energy Efficiency", Ari Sorsaniemi of DG Connect highlighted that 5G could be energy-efficient if, among other conditions, the data transmission in a loaded case is efficient and energy consumption is low when there is no data. This means that the 5G cells need to have the capability to support a high sleep ratio and long sleep duration. Figure 5 illustrates the gains in energy efficiency through the different sleep modes[17].
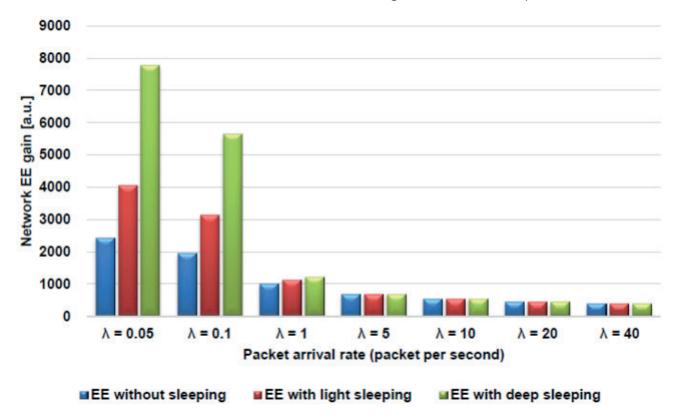

Figure 5: Energy efficiency with sleep mode (Source: "Future Connectivity Systems" DG Connect, EC)

For Dorina Dragomir and Cristina Gheorghe, as stated in their research entitled "Energy efficiency for 5G mobile communications"[18], 5G energy efficiency could be increased through:

› A significant increase in the battery's lifetime.

› The reduction of the base station's power consumption.

› The improvement of energy performance during data transmission thanks to a more user-centric system in which the transmission can be specifically tailored to the intended receiver in a flexible and adaptable way.

Base station power consumption can be reduced through a network topology designed in such a way that when the load decreases, base stations begin to cover more locations, in order to put some base stations in "sleep mode". This has been called the "ultra-lean design", and is based on the "*only transmit when needed*" principle. An ultra-lean design could allow the base stations to have longer periods without transmission, enabling the equipment to have more extensive or deeper "sleep mode" levels.

A more user-centric system based on the "*only*

16 https://onestore.nokia.com/asset/200876.

17 https://docbox.etsi.org/Workshop/2017/20171123_ITU_ETSI_ENV_REQ_5G/KEYNOTE/KEYNOTE_5G_EE_SORSANIEMI_EC.pdf.

18 http://www.agir.ro/buletine/2785.pdf.

transmit when needed" principle is one of the most interesting multi-antenna techniques to improve a network's energy performance. Indeed, it could decrease interference, thereby enabling a reduction of the overall transmission power in networks, and extend service coverage which provides high data rates in sparse deployments of networks.

A combination of these two systems (ultra-lean and user-centric) could enable a greater degree of user-centric network optimization of the active radio links in the 5G network. All these are systems which improve network flexibility and enable the concept of *network slicing*, which can be used for tools like virtualized network functionality and cloud technologies. The energy consumption footprint could be improved for some virtualized network functionality through the enabled improved infrastructure scaling and decrease in computational redundancy[19].

19 http://www.agir.ro/buletine/2785.pdf.

Conclusion

The fifth telecommunication generation, 5G, is about to be implemented in Europe. This technology is very promising regarding its application to the many verticals, and will enable the emergence of innovations. Nevertheless, in a time when it has become important to minimize energy consumption as much as possible, the energy efficiency of 5G is a major concern.

Approaches and solutions for making 5G as energy-efficient as predicted – more than 90% more energy-efficient than LTE – have been widely discussed in the literature. One of the main solutions highlighted in most of the studies on this subject is the possibility to put base stations in "sleep mode" – since base stations consume 80% of the energy used to transmit data[20]. Other solutions include spatial multiplexing, beamforming, improved battery life, reduction of energy consumption by auxiliary equipment, and increased hardware efficiency.

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20 https://onestore.nokia.com/asset/200876.