Energy Footprint of Mobile communications in the 21^{st} century

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Zusammenfassung

Diese Arbeit untersucht die Umweltbelastung des Mobilfunks im 21. Jahrhundert, wobei der Schwerpunkt auf Deutschland liegt. Seit dem Aufkommen von Mobilfunktechnologien, insbesondere mit der Verbreitung von Smartphones und dem Übergang zu 4G- und 5G-Netzen, ist der Energieverbrauch von Basisstationen und Nutzergeräten deutlich gestiegen. Durch eine Analyse der nationalen Energiedaten, der Dynamik der Basisstationen und der Trends bei den Nutzergeräten beleuchtet das Papier die Umweltauswirkungen der Mobilfunktechnologien. Zu den wichtigsten Erkenntnissen gehören der beträchtliche Beitrag erneuerbarer Energiequellen zur Stromerzeugung, der Energiebedarf der Komponenten von Basisstationen und die Herausforderungen bei der Schätzung des Stromverbrauchs von Nutzergeräten. Das Papier zeigt auch Möglichkeiten zur Energieeinsparung auf und betont die Bedeutung nachhaltiger Praktiken bei der Abschwächung der Umweltauswirkungen der mobilen Kommunikation. Um energieeffiziente und umweltverträgliche Mobilkommunikationssysteme voranzutreiben, sind weitere Forschung und Zusammenarbeit unerlässlich.

Abstract

The paper investigates the energy footprint of mobile communications in the 21^{st} century, with a focus on the context of Germany. Since the advent of mobile communication technologies, especially with the proliferation of smartphones and the transition to 4G and 5G networks, there has been a significant increase in energy consumption associated with base stations and user equipment. Through an analysis of national energy data, base station dynamics, and user equipment trends, the paper sheds light on the environmental implications of mobile communication technologies. Key findings include the substantial contribution of renewable energy sources to electricity production, the energy demands of base station components, and the challenges in estimating the power consumption of user equipment. The paper also identifies opportunities for energy saving and emphasizes the importance of sustainable practices in mitigating the environmental impact of mobile communications. Moving forward, continued research and collaboration are essential for advancing energy-efficient and environmentally responsible mobile communication systems.

Dislaimer: This paper has been written with the help of AI tools for translating sources and outlining parts of the written content. All content has been written or created by the author unless marked otherwise.

Contents

1 Introduction

Since around 2010, mobile communication has been a vital part of everyday-life for most of the western world. In 2007, we saw the launch of the iPhone, arguably one of the most influencial inventions in the mobile market ever. With the introduction of 4^{th} generation mobile network (4G) in late 2009 came a massive increase in mobile communication over the internet. For almost one and a half decades, more and more technology has been invented for the mobile phone market.

In addition, the Oculus Rift has ushered in the reincarnation of the idea of Virtual Reality and spacial computing, plainly meaning the usage of 3D-space as a way to distribute user interfaces. More and more, we rely on small, wireless devices with a sleek, modern and fashionable design and people seem to keep buying in. With that in mind, most mobile User Equipment (UE) has had one spatial constraint that has so far never been overcome: Battery life and usage breaks to recharge at a wall socket. This paper focuses on the effectiveness of energy consumption in respect to the overall environmental impact of modern mobile communications. To this end, the following chapter 2 summarizes other work done in the field and its topics. Chapter 3 introduces a definition of environmental footprint and its relevance to this topic. The chapters 4 and 5 go into detail about the energy production and consumption in Germany both in general and related to mobile communications. Chapter 6 then names a few opportunities for saving energy.

2 Related Work

When inspecting the relevance of mobile communications within the global energy market, one can only rely on data given out by nations or leagues of nations. [Umwelt Bundesamt, 2024] gives a summary of the electricity consumption in Germany by year and [DESTATIS Statistisches Bundesamt, 2023a] shows the production of electrical power between 2019 and 2022 by energy source.

[Bayerisches Landesamt für Umwelt, 2024] lists generalized indicators for environmental impact. These indicators are meant to help analyze the effect of any product or project on the environment.

The whitepaper [Huawei Technologies, 2019] is a technical report on the state of Radio Base Station (BS) and gives insight into the power consumption of BS as a whole and parts. The paper also outlines challenges for the construction of site power supply and gives pointers to what efficient power saving strategies could do.

[Shurdi et al., 2021] describe the energy consumption and efficiency of BS in detail and examines the power consumption of switching between a sleep state and an active state.

[Shen et al., 2022] outline the technical changes going from 4G to 5$^{\text{th}}$ generation mobile network (5G) infrastructure. Based on those findings, they propose multiple sleep mode switching policies and gives a comparison between them.

3 Environmental footprint

This chapter gives an outline of the meaning of environmental impact and the metrics for it. First, the section 3.1 summarizes the indicators factoring into the effect on the environment. Second, the section 3.2 gives first answers

Climate and Energy	**Nature and landscape**	**Environment and health**	**Resources and efficiency**
Climate change and vegetation development	Landscape fragmentation	*Air quality*	Waste generation
Carbon dioxide emissions	Species diversity and landscape quality	*Noise pollution*	*Recycling rate*
Energy consumption	Red List species	Road traffic noise	*Resource productivity*
Renewable energies	Area for nature conservation objectives	Freight transport performance	Organic farming
	Agricultural land with high nature value	Local public transport	*Settlement and traffic area*
	Forest condition	Nitrate in groundwater	*Land use*
	Acidity and nitrogen input	Heavy metal input	*Contaminated sites*
	Nitrogen surplus		
	Ecological status of surface waters		

Table 1: 27 Environmental Indicators [Bayerisches Landesamt für Umwelt, 2024], italics are relevant to mobile communications

to the relevancy of those indicators and interprets why some indicators are more relevant to this topic than others.

3.1 Indicators for environmental footprint

When we want to analyze the impact something has on the environment, we need to have consistent metrics to give values to and compare. [Bayerisches Landesamt für Umwelt, 2024] gives 27 general indicators as to what those metrics have to reflect on and are grouped into four categories. Table 1 show all indicators within its category.

For this paper, these indicators will be used to narrow down the topic down to the most relevant factors.

3.2 Relevancy of indicators

On the topic of mobile communications in general, all indicators of the category “Nature and landscape” can be ignore due to the fact that they are not applicable to either BS, cable laying to and from those BS or the UE.

From the category “Climate and Energy”, the indicator Climate change and vegetation development will be ignored due to the BS’ signal outputs’ unproven significance on the vegetation. The effect of BS on the climate change is only noticable through the usage of electicity which is inspected under the other indicators of the category.

The category “Environment and health” only yields the relevant indicators air quality and noise pullution, both mainly dependent on the energy source of BS and UE. The other indicators of the category will be ignore because they are not applicable to mobile communications. The positive effect that mobile communications might have towards the management of traffic and both freight and public transport are not inspected in this paper.

Preliminary tests of eight Radio Base Stations in Eislingen/Fils, Germany, have shown that none of the examined systems contribute to audible noise pollution. Five BSs have been measured with environment noise. These measurements show an average of approximately 40 dBA with an average distance to the antenna systems of 22 meters. Figure 1 shows the minimal, maximal and average noise level of those measurements. Although all units are visible from street level and some have a maximum noise level that would be descernible from background noise, all measurements above 50 dbA are caused by their location, e.g. industry buildings or a train station. No units reach a noise level above 60dbA. Based on this data, noise pollution is considered no factor in the environmental impact of Radio Base Stations.

This paper assumes that only a insignificant number of BS are built on agricultural land and that once built these BS produce next to no waste at all. Therefore the indicators waste generation and organic farming can be left out of this paper. All other indicators from the category “Resources and efficiency” are applicable to the build site and lifecycle of BS and UE and are applicable to mobile communications.

The indicators “Carbon dioxide emissions”, “Air quality” and “Noise pollution” all boil down the source of electical power of the base station and UE. [Huawei Technologies, 2019] implicates that near all BS use whatever electical power they can get on-site and have lithium-ion batteries for emergency-power. With that electrical equipment the effect of those three indicators are dependent on the source on the power grid and therefore dependent on the indicators “Energy consumption” of the equipment and the “Renewable energies” produces for the power grid of the region.

“Settlement and traffic area”, “Land use” and “Contaminated sites”

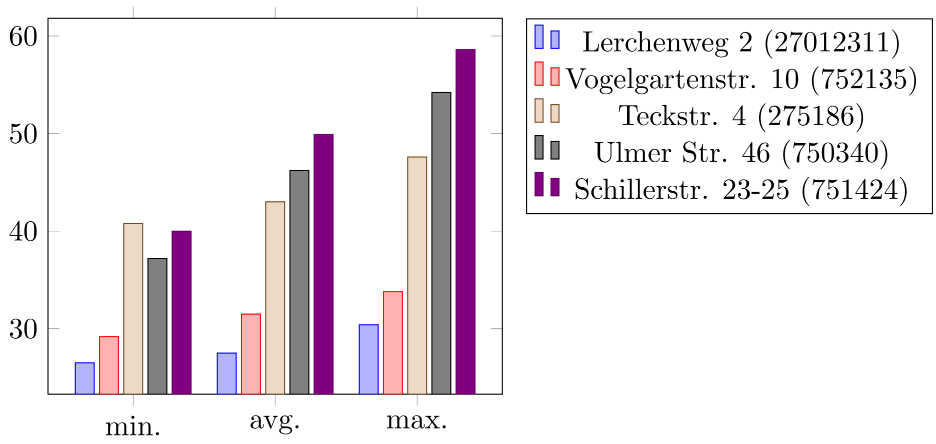


Figure 1: Noise levels of measured BSs in 70354 Eislingen/Fils, Germany. The legend includes the “Standortbescheinigungs-Nr.” of the unit [Bundesnetzagentur, 2024b]. “Teckstr. 4” is the only radio tower.

come down the the area that build site of BS. [Deutsche Funkturm, 2024] states in its advertisement for new build site of BS “Around ten square meters of technical space is required to operate a radio station on the roof, and around 150 square meters of floor space or technical space is required for a mast”. Because it is possible to use already developed areas and effect on the above mentioned indicators is not caused by the building of new BS, the effect of BS can be considered nonexistent.

This means that only four of the 27 indicators are relevant to mobile communications:

1. **Energy consumption**: Energy, electrical and other, consumed per consumer unit and consumption time. Usually measured in kWh per person and year.

2. **Renewable energies**: Share of renewable energy in energy consumption and production (assumed to be equal here).

3. **Recycling rate**: Share of recycled materials in total waste generation.

4. **Resource productivity**: Ratio of gross domestic product to primary energy consumption or raw material consumption in relation to a base year.

The upcoming chapters will only cover the energy consumption and share of renewable energies because the recycling rate and resource productivity outgrow the scope of this paper.

4 Numbers: mobile communication and national power consumption

Having narrowed down the topic of environmental impact of mobile communications down to the power consumed by the equipment and the resources used in production and after usage, this chapter aims to give comparison and numbers filling in the indicators of chapter 3. For the comparison, the assumption is made that the usage and production of base stations is similiar around the world although for the energy consumption and production, the mobile communications and energy markets of only Germany will be inspected.

4.1 National energy data of Germany

In the year 2022, 573.1 TWh of electricity were produced gross, close to 2% less than the three-year average of ca. 584.06 TWh in 2019-2022. Of that, 254 TWh (44%) were produced using renewable energy sources, mainly wind power and photovoltaics [DESTATIS Statistisches Bundesamt, 2023a]. Over the whole year 2022, 11,01% (63,1 TWh) of the greed feed-in were imported [DESTATIS Statistisches Bundesamt, 2024]. In the third quartal of 2022, 10.99% (13 of 118.2 TWh) have been imported and 16 TWh have been exported. The third quartal of 2023 showed an increase of imported feed-in to 23.1 TWh and 9.9 TWh exported power [DESTATIS Statistisches Bundesamt, 2023b].

In 2022, 552 TWh have been consumed gross [Umwelt Bundesamt, 2024] and 490.6 TWh net [Statista, 2024]. Of the gross consumption, 46% have been from renewable energy sources [Umwelt Bundesamt, 2024].

4.2 Base Stations

According to Deutsche Funkturm [2024], a build-site for single BS needs a power supply that can deal with a constant load of 3kW. In Buchheister [2023], Vodafone states to have have built 14200 sites with at least some 5G capabilities and there are 41945 5G Radio Base Stations in Germany [Statista, 2024]. The exact number of BS is probably difficult to determine because there are only very few public technical reports on the expansion to 5G and most of the marketing publications online have no technical information as to which "5G Radio Base Stations" include sites with Long-Term Evolution (LTE) functionality used for Non-standalone (NSA) mode 5G New Radio.

However, it is known that there are 71510 "mobile phone sites" in Germany. This number includes radio sites with LTE (800 MHz), GSM (900 MHz), GSM/LTE (1800 MHz), UMTS/LTE (2600 MHz) and 5G (3600

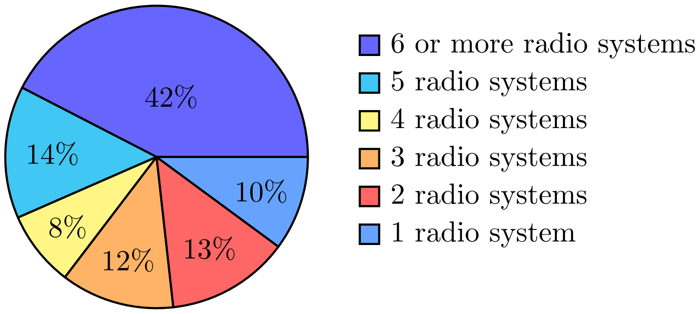


Figure 2: Distribution of radio systems within all Radio Base Station sites in Germany [Bundesnetzagentur, 2024a] (missing one percent due to rounding errors)

MHz) equipment. Figure 2 shows the distribution of number of radio systems on those sites [Bundesnetzagentur, 2024a].

Taking 41945 5G Radio Base Stations and 3kW as our reference number of units and power consumption for 5G under full load, it can be estimated that the total grid load is 125.835 GW. Assuming full load all year around the maximum power consumption can be calculated with 1.1023146 TWh per year or 26.28 MWh per site and year. This results in 0.19969% of the gross and 0.224687% of the net national power consumption. 0.19234% of the national electrical power production is used up by the base stations in the Germany.

Note that the number of 5G base stations in 2022 was enough to "only" cover 79% of the nation's area [Bundesnetzagentur, 2022]. To adapt for a complete coverage in the future, the number of the above paragraph will be multiplied by factor of 1.266 (overlap not included). Also, this calculation assumes a full usage of the power supply at all times without idle time or down time.

4.3 User Equipment

As for the User Equipment, two categories will be differentiate between in this paper: devices actively used by humans and Machine-to-Machine (M2M) communications. There are 8.59 billion mobile phone subscriptions [Richter, 2023] and 7.41 billion mobile phone users, of which 6.93 billion are smartphone users [Turner, 2024].

In Germany, the number of smartphone users in 2022 was 67.6 million [Statista, 2024c], but there have been 104,904 million mobile phone subscriptions (124 per 100 capita [Statista, 2024a]) for the 84.6 million people living in Germany [DESTATIS Statistisches Bundesamt, 2022]. That only describes the mobile phone subscriptions for human-used devices. The total count of subscriptions including M2M devices is 169 million [Statista, 2024],

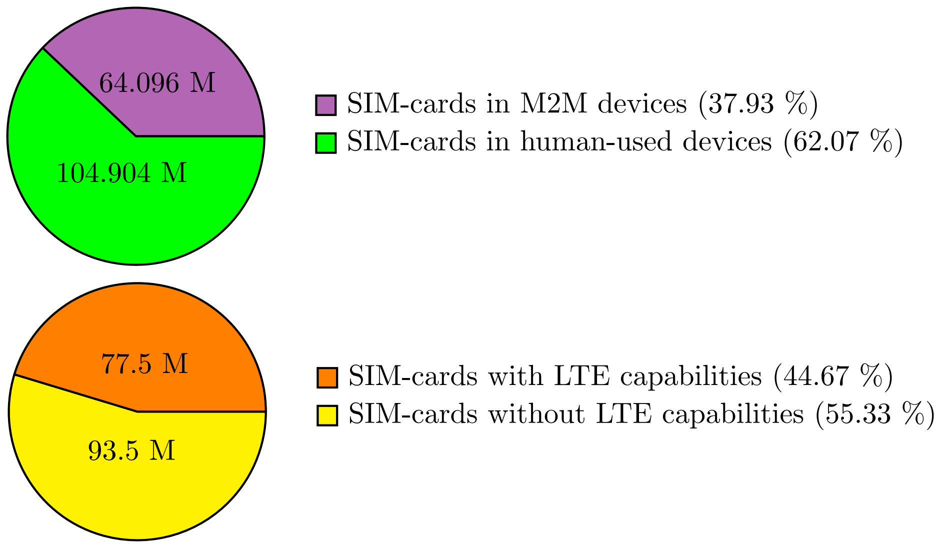


Figure 3: Distribution of SIM-cards in Germany between Machine-to-Machine and human-used devices and between cards with and without LTE capabilities (LTE or more modern), totaling 169 million (M) cards

meaning about 37.93% of mobile communication connections are M2M communication. These number describe the total number of SIM-cards in Germany without specifying wether or not the activity coming from those connections classify as "modern". Only 44.67% of the total number of SIM-Cards in circulation in Germany (77.5 million [Statista, 2024b]) have some form of LTE functionality (see Figure 3).

When it comes to the devices used for mobile communication, the situation is opaque. Very little is known about the devices in use and their specifications in M2M communication (47.93%). There only is some information of human-used devices that helps estimate the number of eligable and active devices. The first smartphone with 5G capabilities entered the German market in march of 2019 [yourfone, 2024]. Since the beginning of 2019, 87.9 million smartphones have been sold in Germany until 2022 (22.1 million in 2019, 22 million in 2020, 22.2 in 2021 and 21.6 million in 2022) [Statista, 2024]. The share of smartphones with 5G capabilities is unknown.

The number of other human-used devices is about as opaque as the M2M devices. It is known that there have been only 19 models of 5G-capable tablets in the German market (beginning in November 2021) [Linsner, 2024] and 3 5G-capable laptop models [5G-Anbieter.info, 2024]. The number of other User Equipment, e.g. wearables, remains unclear.

All this makes the calculation of the power demand by User Equipment very difficult. It is not possible to make a reliable and accurate statement about the power consumption for those devices. However, it is possible to make an estimation under some assumptions. Firstly, the assumption will be made that the average power consumption of modern smartphones is a good estimation for the power consumption of any UE. In order to reconsile with this assumption two calculations will be made: One for all devices and one only for human-used devices. Secondly, the share of SIM-cards with/without LTE capability remains a constant throughout the User Equipment space, meaning the share of 44.67% can be used across all devices types. This seems a good assumption because it is unclear with the currently available information to know more about the actual situation and it seems improbable that all 64.096 million M2M devices have SIM-cards with LTE capabilities, leaving only 11.404 million for human-used devices.

With those assumptions established and the information that the charging of a smartphone consumes an average of 3.65 kWh per year (10 Wh per over-night charge for 365 days per year) [GASAG AG, 2024], the estimation of the power consumption of UE is as follows: The 104.904 million human-used devices in Germany consume 382.8996 GWh per year and the total 169 million UE devices in Germany consume 616.85 GWh per year. Of those, we are only concerned with the devices participating in modern mobile communications (44.67%), bringing those numbers down to 171.041 and 275.547 GWh respectively.

5 Sources of energy consumption

In order to outline the opportunities for saving energy, this chapter gives details about what parts of Radio Base Stations and User Equipment consume most of the power. The following chaper 6 then describes five technologies that either increase efficiency or save power entirely.

5.1 Base Stations

The parts of a modern BS can be seperated into several units. The antenna system and Remote Radio Unit (RRU) are capable of convertimg and sending a baseband signal as a radio signal and the Building Baseband Unit (BBU) modulates a signal from and onto the used radio frequency. The physical support system includes all components to keep the antenna system, RRU and BBU running, e.g. the power supply, backup batteries, transmittion equipment like cables and converters and Air Conditioning (AC). Due to the current situation, in which the BBUs can have some distance to the antenna systems and RRU and can supply more than one, the antenna system and RRU are often combined to a Active Antenna Unit (AAU) and BBUs are differentiated between Centralized Unit (CU) and Destributed Unit (DU).

Figure 4 shows the power consumption by BS unit and traffic load and the power consumption of each unit in a deep sleep mode. The power con-

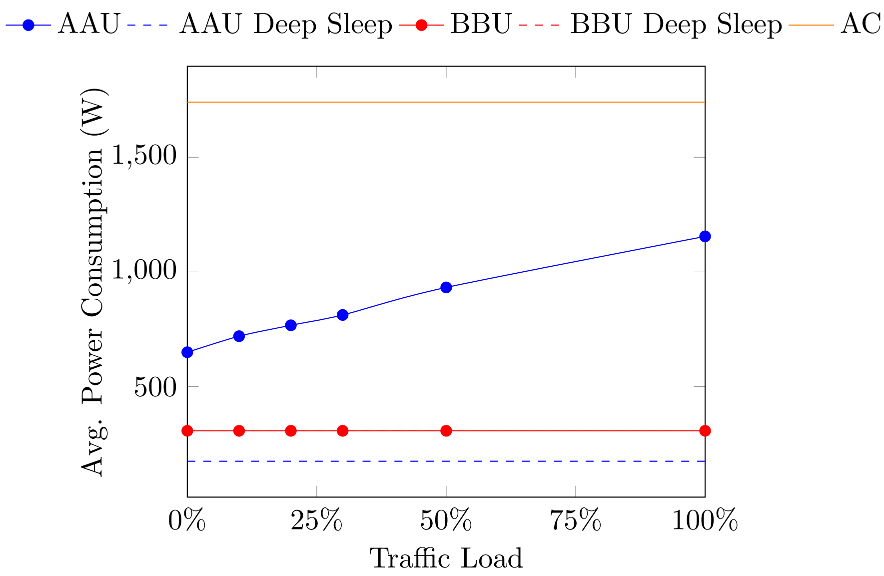


Figure 4: Average power consumption of AAU, BBU and AC by traffic load and its respective deep sleep power consumption [China Telcom and ZTE, 2022]

sumption of the the AC is shown seperately from the other physical support equipment because the rest has a power consumption of next to zero. Note that the power consumption of the BBU and the AC are static and more importantly independent from the traffic load. For the Air Conditioning, Radio Base Stations have the specific demand of disabling the AC on low traffic times or when the environment is cold anyways, which is sensible. On the other hand, the demand for power saving to be dependent on traffic load usually concerns short time intervals, e.g. few milliseconds or seconds, which is shorter than the average reaction or effect time of a Air Conditioning unit.

Because this seems obvious and managable during research, the question is raised whether this can be true. During research, no answer was found on this question and no operator of BS was willing to answer questions.

5.2 User Equipment

The power consumption of a modern smartphone varies largely based on the used hardware parts and software optimizations. While some sources from the past decade claim the power usage of a CPU to vary between 500 and 2000 mW [Warden, 2015], other sources see these numbers between 55 and 612 mW [Perrucci et al., 2011] or 5.1 nd 11.1 mW [Tawalbeh et al., 2016] (note that different CPU models were used in the sources). This discrepency continues with other components like the display (400 mW on average [Warden, 2015], 1000-1500 mW [Maluf, 2015] or 63-527.05 mW [Perrucci et al., 2011]) or writing data to storage (400 mW per MB [Maluf, 2015] or 580 mW per MB [Perrucci et al., 2011]).

In general, the power consumption caused by mobile communication or downloading data through 3G (at 1 Mbps) or WiFi (at 4.5 Mbps) is independent from other hardware components [Perrucci et al., 2011]. The power draw of an active cell radio is 800 mW on average [Warden, 2015]. This results in a power usage of 1400 mW and 1450 mW for 3G download or WiFi download respectively (including writing the data to storage) [Perrucci et al., 2011].

Torchiano et al. [2013] hint at the possibility to save energy through software. The paper shows that it is possible to save power based on energy profile setting and reduce the consumption by a factor between 2 and 7.

Because the numbers vary this much by used hardware components and usage and because further research into this topic will go beyond the scope of this paper, the power consumption of User Equipment is not further examined.

6 Energy saving opportunities

This chapter goes over oppertunities and gives an overview over 5 solutions to either increase the efficiency of mobile communications or to save power. Each section gives a short introduction into how the solution works and how it can improve the environmental impact of its participants.

6.1 Giga-MIMO

Giga-MIMO increases the number of concurrent connections between transmitting antenna and receiving User Equipment devices through beamforming. It uses another frequency band than massive MIMO (7-16 GHz) and increased range [3gp, 2022].

This technology does not decrease the power consumption of the Radio Base Station but rather improves the capacity and therefore the efficiency of the antenna system. It increases the "bang for the buck" on unfull traffic load and the battery lifetime of the BS because the batteries discharge completely less often by switching off parts of the Giga-MIMO antennas [Qualcomm, 2022].

For 6G, the goal is to make better use of Giga-MIMO and improve the technology [3gp, 2022].

6.2 NR-Light

New Radio Light (NR-Light) is a standard in communication between BS and UE with less capabilities in capacity, complexity and power usage. I uses the software improvements of 5G with less hardware capabilities. With less demand for technological advancements comes a lower power consumption. Broad usage of NR-Light reduces the power consumption of a Radio Base Station and increases the efficiency of the antenna system for devices with reduces demand [3gp, 2022].

6.3 Reduced Capability NR

NR-Light enables reduced power consumption through reduced capabilities within an BS, whereas Reduced Capability NR (RedCap) reduces power consumption through reduced capabilities within the UE (150 Mbps DL / 50 Mbps UL, 13-30ms latency). RedCap used a smaller maximum device bandwith, fewer needed device receive branches, fewer downlink MIMO layers, a smaller downlink modulation order and fewer options for duplex operations [3gp, 2022]. It improves the efficiency of UE with fewer demand of the communication systems, e.g. wearables and drones. RedCap devices can use 5G infrastructure with less capable and power-intensive hardware.

6.4 NR Sidelink

NR Sidelink is based on LTE Sidelink and enables Device-to-Device (D2D) communication instead of Network-to-Device (N2D) communication for UE. Therefore NR Sidelink enables Distributed Networking as well as mobile "Distributed Base Stations" [3gp, 2022]. This means that parts of the functions of a BS, such as connection management, are handled by the UE. Device-to-Device also enables chained connections where devices act as deputy Radio Base Stations, which improves capabilities for fast construction of networks, e.g. for emergency services like fire departments on duty.

Device-to-Device communication allows for the BS to be taken out of the loop and save energy. It is possible to use NR Sidelink connections for all User Equipment, but not all UE supports conversion between N2D and D2D communication and serving as a deputy BS.

NR Sidelink improves the efficiency of Radio Base Stations through greater range, increased capacity per BS connection and data offloading from the BS. It decreases the power consumption of the BS by **not** going through the BS.

6.5 Sleep Modes

Lastly, smart usage of sleep modes has the potential of saving energy by shutting off parts of a BS's hardware or software. For the purpose of decreasing the environmental impact of a BS, 5 different modes can be differentiated between: Active DL, Active UL, Microsleep/Idle, Light Sleep and Deep Sleep. Table 2 compares the power usage of these modes relative to each other and the transition times from the sleep mode to active transition. It shows the

Power State	Relative power P	Total transition time T [ms]
Deep Sleep	1	50
Light Sleep	25	6
Microsleep/Idle	55	0
Active UL	110	N.A.
Active DL	280	N.A.

Table 2: Relative power consumption (arbitrary units) and transition times to active transmission of sleep modes [Zhu, 2023]

great potential of sleep mode usage in power saving and compares it to the user experience through transmittion latency.

Figure 5a shows the traffic load of a BS within a 24 hour window. It is clear that there is a great difference in demand for hardware and software between times with high traffic and times with low traffic. Figure 5b shows the energy consumption of different sleep mode activation strategies (algorithms that determine when and which sleep modes is to be activated). Some strategies achieve more similarities to the actual traffic load. The problem with choosing a sleep mode activation strategy is the contrariness between saving energy whenever possible and decreasing latency for better user experience. Optimizing this problem is the greatest challenge as every powered off component saves power.

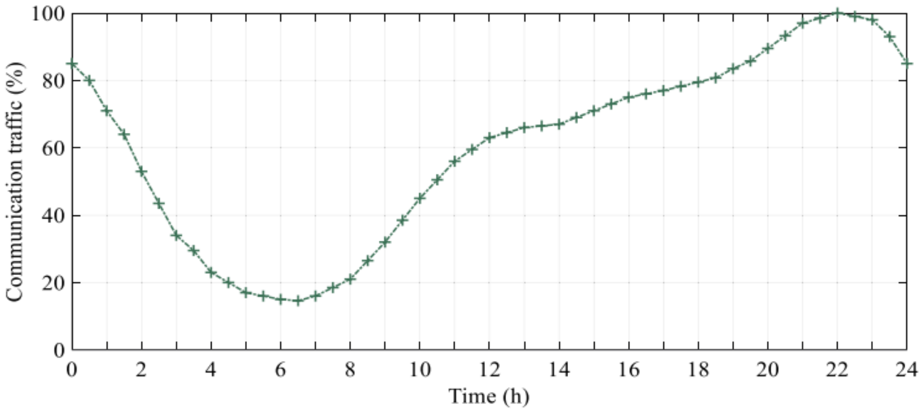
7 Summary

In this paper, we have delved into the energy footprint of mobile communications in the 21^{st} century, focusing primarily on the context of Germany. This research reveals several key findings and implications that are worth summarizing and reflecting upon:

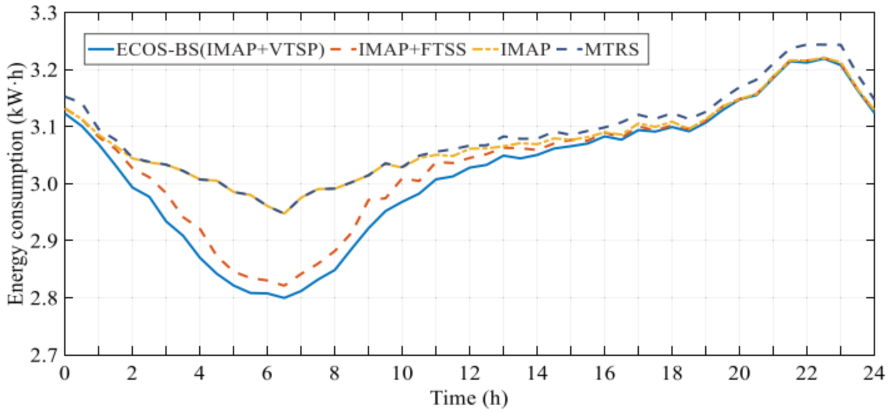
1. Environmental Footprint: By delineating relevant indicators for environmental footprint assessment, energy consumption and the share of renewable energies have been identified as crucial factors in evaluating the environmental impact of mobile communications. The focus on these indicators underscores the need for sustainable energy practices in the mobile communication sector.

2. Energy Consumption and Production: The national energy data of Germany has been scrutinized particularly emphasizing the production and consumption of electricity. Notably, renewable energy sources have accounted for a significant portion of electricity production, on which mobile communications bases its renewable energy share.

3. Base Stations: The analysis of base stations underscores their energy demands. The distribution of radio systems within base station sites



(a) Communication traffic in a heterogeneous cellular network [Ma et al., 2023]



(b) Communication traffic in a heterogeneous cellular network [Ma et al., 2023]

Figure 5

and the average power consumption of AAUs, BBUs, and AC units provide insights into their operational dynamics and energy requirements.

4. User Equipment: Despite challenges in obtaining precise data, an estimation of the power consumption of user equipment has been attempted, considering both human-used devices and M2M communication devices. While uncertainties persist, our analysis sheds light on the overall energy consumption associated with user equipment.

5. Opportunities for Energy Saving: We have outlined potential avenues for energy conservation in mobile communications infrastructure and devices. Strategies such as optimizing power consumption during low-traffic periods, e.g. through the smart usage of sleep modes, and enhancing the efficiency of base station components present tangible

opportunities for reducing energy consumption and minimizing environmental impact.

6. Future Directions: Moving forward, there is a pressing need for continued research and action to address the energy footprint of mobile communications. Future studies could explore innovative technologies and policies aimed at further reducing energy consumption, increasing the integration of renewable energy sources, and promoting sustainable practices throughout the mobile communication ecosystem.

In conclusion, This examination of the energy footprint of mobile communications underscores the complex interplay between technological advancements, energy consumption, and environmental impact. By fostering collaboration among stakeholders and prioritizing sustainability, we can work towards a more energy-efficient and environmentally responsible mobile communication landscape in the 21st century and beyond.

A Acronyms

3G	3rd generation mobile network.
4G	4th generation mobile network.
5G	5th generation mobile network.
6G	6th generation mobile network.
AAU	Active Antenna Unit.
AC	Air Conditioning.
BBU	Building Baseband Unit.
BS	Radio Base Station.
CPU	Central Processing Unit.
CU	Centralized Unit.
D2D	Device-to-Device.
DL	Downlink.
DU	Destributed Unit.
LTE	Long-Term Evolution.
M2M	Machine-to-Machine.
MIMO	multiple-input and multiple-output.

N2D	Network-to-Device.
NR	New Radio.
NR-Light	New Radio Light.
NSA	Non-standalone.
RedCap	Reduced Capability NR.
RRU	Remote Radio Unit.
UE	User Equipment.
UL	Uplink.
WiFi	Wireless Fidelity.

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