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5G Energy Efficiency Overview

Olimpjon Shurdi
Luan Ruci
Aleksander Biberaj
Genci Mesi
Polytechnic University of Tirana, Albania

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Abstract

It is a critical requirement for the future of 5G communication networks to provide high speed and significantly reduce network energy consumption. In the Fifth Generation (5G), wireless cellular networks, smartphone battery efficiency, and optimal utilization of power have become a matter of utmost importance. Energy-efficient networks along with an energy-saving strategy in mobile devices play a vital role in the mobile revolution. The goal of energy efficiency, apart from its ecological value, is also associated with the reduction of operational expenses for mobile network operators, as well as with greater customer satisfaction thanks to increased battery life. Battery and power are an area of significant challenges considering that smartphones are nowadays equipped with advanced technological network features and interfaces. These features require a lot of simultaneous power to make decisions and to transfer information between devices and networks to provide the best user experience. Furthermore, to meet the demands of increased data capacity, data rate, and to provide the best quality of service, there is a need to adopt energy-efficient architectures. The new strategies should not only focus on wireless base stations, which consumes most of the power, but it should also take into consideration the other power consumption elements for future mobile communication networks, including User Equipment (UE). In this paper, we do an overview of power consumption and improvements made so far on the networks and user equipment side and provide our proposals on how to overcome these power-

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hungry issues on the newly 5G systems.

Key Words: 5G, Rel-15, NR, LTE, Embb, Smartphone, Battery, Power Optimization, Energy Consumption, Energy Efficiency, Network Efficiency

Introduction

This paper brings a general overview of smartphones power consumption issues on implementations of currently new 5G technologies. This has been and is on our focus for several years now and looks to continue still till 5G will get mature enough from that perspective.

Energy efficiency is defined as the opposite of the energy consumed per transmitted bit, or as the number of bits transmitted for every unit of energy consumed. In the communications space, power consumption and the resulting energy-related pollution are becoming major operational and economical concerns. The exponential increase, projected in network traffic (data) and the number of connected smart devices, make energy efficiency extremely important. Thus, increasing energy efficiency in mobile networks will reduce the costs of capital and operational expenditures. This as well will have to consider the user equipment (UE) part. On 3GPP Release 15 [as of 3gpp.org], bands are specified in two Frequency Ranges (FR). FR1 ranges from 450 MHz to 6000 MHz, known as cmWave. Bands in FR1 are numbered from 1 to 255 and are commonly referred to as Sub-6Ghz. FR2 ranges from 24250 MHz to 52600 MHz; bands in this set are numbered from 257 to 511 and commonly referred to as mmWave. The initial roll-out of 5G mmWave New Radio (NR) is focused on enhanced Mobile Broadband (eMBB) to increase the data bandwidth and efficiency of connections using a different set of radio frequency bands, enabling better download and upload speeds and less latency compared to 4G/LTE network. Ultra-reliable Low Latency Communication (URLLC) focuses on highly latency-sensitive or mission-critical use, such as factory automation, remote robotic surgery and driverless autonomous cars etc.

The new 5G system needs to adapt and allow devices and network components to make smart decisions proactively. For example, the network should decide whether to use data using LTE or 5G technology for specific services or applications, using metrics such as remaining battery level, RF strength, network load, and resource availability, to provide the best user experience and create a path for both network and device power efficiency. Network operators and device manufacturers have always considered power performance and efficiency to be one of the critical 5G features for optimization and have continued to drive energy-efficiency network ideas into 3GPP standards. The Radio Access Networks (RAN) manufacturers are developing smart sleep mode technology to guarantee that the radio hardware only transmits radio frequency signals when needed and can achieve up to 15% of the energy from software features only [Lauridsen et al 2016].

Fast transitions between sleep and active modes and short active time with high data rate together with low sleep mode power consumption are required to guarantee multiple years of a lifetime for a small low-cost battery. Connected Mode Discontinuous Reception (CDRX) and Discontinuous Reception (DRX) for example, allow UEs to make signaling free transitions between sleep and awakened states. Base stations (gNB or RBS etc.) do not schedule transmissions during the off period of the DRX cycle [3]. Currently, network operators use the Short and Long DRX cycle, where the UE starts with the Short DRX cycle and transitions to the long DRX cycle after a timer expiration. The base stations can direct the UE into DRX mode. CDRX is even more critical as it allows the UE to go to sleep while in connected mode, also by minimizing network connections, signaling, and consuming less battery [15].

The paper is structured as follows. In Section II, we describe the background and related works of such area. There are huge works and investments from vendors and since it’s a new system it is not easy to find related works published from other authors. In Section III, we analyze and look on energy-related issues and proposals made on BTS and Smartphones. In Section IV, we provide our conclusions and upcoming related works.

Background & Related Works

The optimization of already deployed 5G mmWave networks is still at an early stage of work; there is not much data available for analysis issues and identification of areas for improvement. We were not able to find much research work related to impacts of mmWave and 5G NR on battery life. Authors in [Lähetkangas et al, 2014] analyzed the UE battery status and propose that UE proactively modifies the UE capability report before sending it to the network helps in reducing the size of the RRC message to avoid issues like the message buffer overflow. Authors in [Thantharate et al, 2019] provide a survey on advanced research based on an overview of green 5G techniques and energy harvesting in order to exploit multiple technological advantages from an ecosystem of interoperable technologies. Authors in [Wu et al, 2017] have surveyed multiple techniques of power optimization focusing on the use of relays and small cells. They also highlight the importance of simultaneous wireless power and information, MIMO and millimeter-wave.

Authors in [Abrol et al, 2016] analyzed how microsleep, Discontinuous Reception and Transmission (DRX and DTX), and a wake-up receiver concept can be combined to enhance the battery life of 5G mobile terminals by 20%. 80% and 90% respectively. S. Rostami et al. in [Rostami et al, 2018] aims at the reduction of cellular downlink (DL) power consumption,

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of discontinuous reception, by up to 30%, with the introduction of minimal wake-up signaling in 5G networks.

5G Energy Related Issues And Proposals

Since 5G is currently new (started live operations on some network operators from 2019), there are still ongoing works for standardizations. There is a real focus on the energy part. This Energy must be considered from a network point of view and specifically on BTS (or called gNB, NR, RBS etc), and UE or called Smartphones. We will divide our observation on Energy into two main parts: on BTS and UE part, and from HW and SW point of view each.

The list of ongoing works and feature implementation is huge, and we bring in this paper only some main topics regarding it. Note that there is a huge difference between non-standalone (NSA) and standalone (SA) BTS configurations. Where in the 2nd one (SA, standalone mode) the BTS is using its own 5G Core Network. This brings a major improvement on signaling, synch messages and latency for end-user. The 5G UE will be able to synchronize much faster. This will save energy because it will reduce the total "ON" time.

Base Station power consumption

Base station resources are generally unused 75 - 90% of the time, even in highly loaded networks. 5G can make better use of power-saving techniques in the base station part, offering great potential for improving energy efficiency across the network.

Today, we see that a major part of energy consumption in mobile networks comes from the radio base station (BTS) sites and that the consumption is stable. This raises an obvious question: if the base stations are spending so much of their time not transmitting user data, why are they still consuming energy all the time? The reason for this is that most of the hardware components of BTS remain active so that they can transmit mandatory idle mode signals that are defined in the 4G or 5G standards such as synchronization signals, reference signals, and system information.

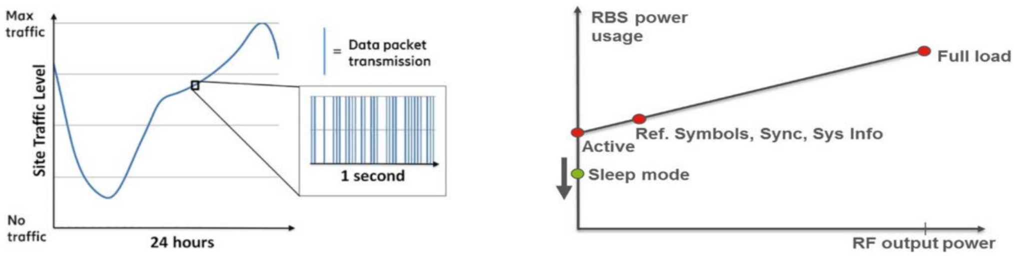

Figure 1. Varying network traffic load during the day (a) and Base station power model (b)

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The model shows that there is significant energy consumption in the base station even at the times when there is no output power i.e. when the base station is in an idle state as it shown in Figure 1.

According to Huawei data on RRU/BBU needs per site, the typical 5G site has power needs of over 11.5 kilowatts, up nearly 70% from a base station deploying a mix of 2G, 3G and 4G radios. Figure 2 illustrate the trend of energy consumptions. 5G macro base stations may require several new, power-hungry components, including microwave or millimeter-wave transceivers, field-programmable gate arrays (FPGAs), faster data converters, high-power/low-noise amplifiers and integrated multiple inputs multiple output (MIMO) antennas. The bottom line is that, in an increasingly 5G world, Communication Service Providers (CSPs) will face significant growth in their energy bills," writes MTN Consulting. So 5G at initial phase will bring a need as well for more power on BTSs which is planned to be reduced in the next releases [9]. We will talk in the next subsections only on two main contributors in reducing power on BTS: deep sleep mode and beamforming.

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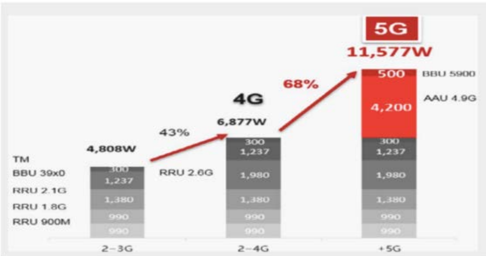

Figure 2. Site power equipment 2-4G and 5G

Energy-saving features of 5G New Radio

The 5G NR standard has been designed based on the knowledge of the typical traffic activity in radio networks as well as the need to support sleep states in radio network equipment. By putting the base station into a sleep state when there is no traffic to serve i.e. switching off hardware components, it will consume less energy. The more components that are switched off, the more energy we will save. NR or 5G BTS, on the other hand, requires far less transmissions of always-on signaling transmissions. This, in turn, allows for both deeper and longer periods of sleep when there are little or no ongoing data transmissions, which has a significant impact on the overall network energy consumption.

Advanced "sleep" modes

One of the most significant developments associated with 5G is the widespread use of deep Sleep Modes. The basic principle is simple: to selectively turn off one or more devices in the absence of traffic. On this topic,

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4G was limited due to the design of its radio interface, a base station that must transmit reference signals about 1,000 times per second, even without an active mobile in the cell [10], [11]. 5G, on the other hand, provides for the configuration of transmission-free time slots in non-traffic conditions, to enable activation of more advanced and energy-efficient Sleep Modes. An interval without transmission can be set to a range of 5-100 ms, but this means that a terminal can take more time to hang on to a cell – without the user noticing it.

Built-in antennas for more efficiency

Multiple input multiple output (MIMO) is a technology that uses multiple antennas configured in a two-dimensional phased array. The antenna system is attached to a base station and controls the transmission and reception of radio signals. Massive MIMO systems or mMIMO are expanded MIMO systems with up to several hundred antennas (like 8, 16, 64 or 256) and can handle large volumes of network throughput and support large numbers of client connections. Massive MIMO antennas can transmit the signal only in the direction of the communicating mobile (known as beams), rather than over a wide area as the antennas commonly used in 4G do. This feature significantly increases the throughput delivered by an antenna, as multiple beams can be used simultaneously, each being able to reuse the cell's frequencies. They concentrate the power amplifiers (whose efficiency has been improved compared to 4G) at the radome by combining radiating elements, analogue electronics, and a digital part dedicated to beam management functions. While a 5G antenna consumes three times more energy on average today than a 4G antenna, this ratio is expected to drop to 50% by 2021 and 25% by 2022. Above all, for this energy consumption, a 5G antenna manages a bandwidth five times higher and can deliver a higher throughput to serve more users simultaneously, which on the other side means less time in downloading or uploading data for end-users (and less power consumption for them).

Beamforming is a technology that can direct radio transmission signals in a specific direction. This increases the channel efficiency, data rates, reduces interference and focuses radio energy directly at the client devices. Since the massive MIMO antennas and base station systems communicate with remote clients using a focused beam, the wireless protocols can calculate the minimum power required for communication. This reduces the energy consumption for wireless energy transmissions for both the base station and the client devices. As a result, 5G networks using beamforming consume about four times less power than comparable 4G networks [10], [11] and [15].

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UE Energy analysis and proposals

Next, we will talk about smartphones or user equipment part, their pain points and improvements on energy consumption part.

Device energy consumption – HW part

Most 5G phones offer big batteries owing to the increased power consumption of early 5G modems and connectivity. But just how much more power does a 5G phone need over a 4G device? Redmi general manager Lu Weibing [12] has taken to Weibo to answer this question, claiming that today 5G phones consume ~20% more power than a 4G phone. This suggests that a 20% increase in battery size is needed for a 5G phone to achieve the same endurance as a 4G variant (assuming everything else is equal). Also, Qualcomm‘s flagship 800-series processors consume 20% more “juice” than an upper mid-range Snapdragon 700-series chipset. So, when taken together, this means a 5G flagship will consume significantly more power compared to a mid-range 4G smartphone, which means that battery capacity and optimizations are key for high-end 5G phones.

Adopting a “sandwich” motherboard design and ultra-thin in-display fingerprint sensor is the key to make more space for the phone’s bigger batteries (in mAh and consequently in size) in order to overcome such issues for now.

UE Energy Consumption and Wake Up Time

Reduced physical layer latency can be utilized to reduce energy consumption of the network devices. Recent measurements on LTE smartphones (and 5G for NSA configurations), have shown that the power consumption ratio between the UE being “ON” and “sleeping” modes is at least 1:35. Maximizing the UE’s sleep time is therefore essential to improve the battery life. When the UE wakes up from the low-power sleep mode to receive or transmit data it follows the procedure illustrated in Figure 3.

From power consumption perspective, the procedure can be divided into five different states: sleeping, waking up (wup), synchronizing (sync), transferring data, and powering down(pd). The states are illustrated in Figure 3. The power-up/down states when changing from sleep to active mode and vice versa are device and user-dependent, and not significantly affected by the wireless standard. Due to the shorter frames and the enabled allocation of synchronization signals in every frame, the 5G UE will be able to synchronize much faster. This will save energy because it will reduce the total ON time. The time to transfer data in 5G will also be shorter compared to LTE due to the increased data rates, which reduces the actual transfer time. Furthermore, it has been specified that the base station has at least 4 ms to process the data

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before it transmits an ACK/NACK, and therefore the total time for single data transmission is estimated to be at least 10 ms.

In practice, the actual wake-up from sleep to RRC connected state also requires radio RRC connection setup procedure with the establishment of radio bearers. In the 5G concept, due to the bidirectional control plane embedded to each frame, the UE initiated data transmission/reception can be achieved within 5 frames +1 symbol.

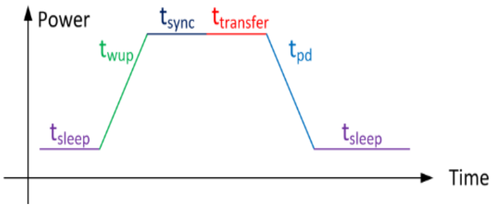

Figure 3. UE power states during a transmission period

Due to the short frame length, the total time required for this procedure is estimated to be ~1.27 ms (with 0.25 ms frame length) or even shorter with shorter frame length.

Figure 4 below shows the results of theoretical numerical calculations of the battery life as a function of synch and reception opportunity times and the number of transmissions per second. Results are presented for both machine-to-machine(M2M)-optimized LTE [Tirronen et al] and 5G systems with different frame structures but with same power consumption values and with 32400 Ws low-cost battery. In the transmission phase, the 5G UE is assumed to follow the procedure according to Figure 5. In the reception phase, the UE is assumed to perform only synchronization and thereafter receive a short paging message with a length of one OFDM symbol. Based on Figure 5 we can conclude that it is obviously more efficient to use the proposed 5G system over LTE due to the aforementioned reasons.

Device energy consumption due to monitoring purposes

NR enables higher data rates and lower latency, which allows user data sessions to be terminated faster than in LTE. This inherently reduces the associated energy consumed by the device per transmitted bit. However, since data arrival patterns are not deterministic, the device also monitors the physical downlink control channel (PDCCH) for possible data scheduling information during periods when data is not scheduled. With similar settings, NR and LTE device energy consumption for control channel monitoring in connected mode does not differ significantly. However, invoking new performance-enhancing features in NR (wider BWs, shorter slot times, multiple scheduling events per slot, etc.) can also increase the energy cost of control channel monitoring.

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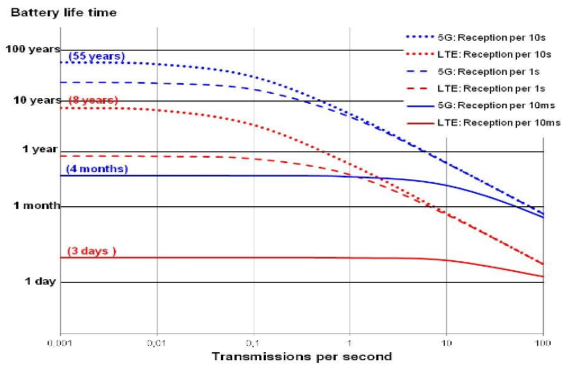

Figure 4. Battery lifetime comparison between LTE and 5G

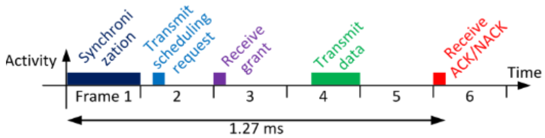

Figure 5. UE initiated procedure for transmission in 5G

Therefore, the first NR specification Rel-15 includes numerous tools for saving device power and energy, such as inactive state, connected-mode discontinuous reception (cDRX), and customized control channel monitoring. 3GPP companies have developed a mutually-agreed device power model that captures the relative powers associated with different active operations, to the lowest power, deep sleep mode. Undoubtedly, reducing the fraction of time for the device to perform unnecessary PDCCH monitoring and enabling the device to be in a sleep state instead offers a high potential for energy conservation.

Figure 6 presents the accumulated energy consumption profile of a typical eMBB device operating in a variety of states in a mix of traffic events over 24 hours. The left-hand bar graph shows, starting from the top, the fraction of energy consumed while performing control channel monitoring, data reception, periodic activities in connected and inactive modes, and deep sleep. The right-hand bar graph indicates the fraction of total time spent performing the respective operations. Despite the relatively short time fraction spent in the connected mode, the energy spent waiting for additional data arrival dominates (usually it is the time after transfer). This is the cost of maintaining the required responsiveness to data arrival in the baseline Rel-15 framework. As illustrated in the Figure 6, by avoiding unnecessary control channel monitoring, we can achieve savings in the device's total consumed energy.

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Energy consumption in mmW deployments

An important advantage of NR compared to LTE is that it allows deployments over a wide frequency range – from below 1 GHz to over 50 GHz (millimeter-wave, mmW) as noted from data in Table I. Using FR2 (over 7GHz) bands, the NR device can exchange data over a significantly wider carrier bandwidth and achieve very low scheduling latencies, realizing the promise of multi-Gbps data rates of 5G for eMBB devices. There are power aspects that may pose challenges in FR2 compared to FR1:

- wider operating bandwidth and efficiency differences of radio frequency circuitry,
- shorter slot times that raise the required number of decoding operations per time unit,
- additional beam management measurements to maintain connectivity between narrow transmission and reception beams of the base station and the device.

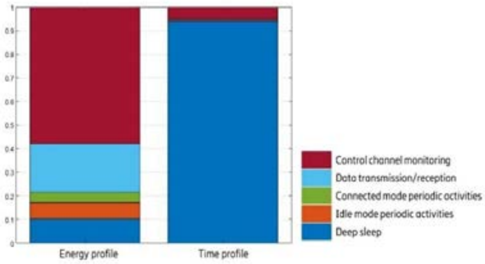

Figure 6. Typical eMBB device energy consumption profile over 24h

The instantaneous power associated with control channel monitoring in FR2 bands is 75 per cent higher than in FR1. However, since the data transmission can be completed much faster, the total energy consumed for transmitting a data burst of a given size utilizing FR2 may become lower than in FR1-only setups. A decisive aspect that affects the overall impact on energy consumption by adding FR2 carriers is, therefore, the network’s ability to dynamically activate the FR2 carrier only when it is needed for actual data transmission, and to instruct the device to monitor the FR2 control channel only when data may be present there. The short TDD latency achieved with the proposed 5G frame structure with very short frame length enables short UE initiated data transmission/reception times, such as <1.5ms, including synchronization, scheduling signaling and actual data transmission with acknowledgement. This is a significant improvement compared to LTE and it enables devices to be in the energy-efficient sleep mode for most of the time, consequently leading to very long battery life.

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Different proposed SW solutions like Connected-mode Wake-Up Signal (WUS), Secondary cell dormancy, Device assistance for secondary cell release and many others are on the way.

Power consumption (relative units)		
Device power states and operations	**FR1 (below 7 GHz)**	**FR2 (mm-Wave)**
Deep sleep	1	1
Light sleep	20	20
Micro-sleep	45	45
PDCCH monitoring only	100	175
SSB measurements	100	175
CSI-RS measurements	100	175
PDCCH+PDSCH reception	300	350
Uplink transmission (depends on TX power level)	250 - 700	350

Table 1. DEVICE POWER CONSUMPTION IN DIFFERENT OPERATIONS AND STATES (TR 38.840)

Conclusions

In this paper we have presented a brief overview of energy consumption challenges in currently new 5G technology and networks, and we concluded as follow:

5G technologies allow a hundred times more traffic to be carried, without increasing the total energy consumption of the network. Early deployments of 5G may lead to increases in energy efficiency if 5G is added on top of an existing network without modernizing the underlying 2G/3G/4G networks. 5G enables new functions and major performance improvements, but it also puts tougher energy requirements on mobile devices. New technologies are being deployed in Mobile network infrastructures and user equipment's to reduce power consumption. These include cloud and virtualization technologies, new efficient antenna hardware, 5G small cell network architectures and more efficient network protocols.

Vendors should continue to improve network configurations and introduce more advanced mechanisms in upcoming product (HW and SW) generations, using mechanisms available in the standard, based on both our own network operation analysis and information from device partners. Advances will also happen on the device front as device architectures and implementations become more mature. The combined effect of advanced network mechanisms and improved chipsets is expected to further enhance NR device energy efficiency in FR1 and FR2 setups, as well as in FR1-only configurations. We foresee that this can be achieved without compromising traditional network performance KPIs such as throughput and latency.

Artificial Intelligence and Machine Learning solutions (AI/ML) will further help to minimize network power consumption by shutting cells down

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in an intelligent way. AI-based optimization can learn from live network traffic patterns to set up specific schemes for power saving groups for different regions in different time zones. These schemes include optimized power-saving trigger conditions. The solution makes the best use of energy while minimizing any effects on quality of service.

The goal for 5G devices is the increase in battery life with:

- At least three days for smartphones
- Up to 15 years or more for cellular IoT devices

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