Power consumption evaluation using 5G energy saving technique: C-DRX

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***Abstract*— The fifth-generation mobile introduced the use of higher frequency wave with the purpose of increasing the network speed as well as the data rate. The aforementioned purpose enables a range of new applications and services like portable virtual reality (VR), augmented reality (AR) and Health. There are many challenge points for mobile devices in 5G and one of the most critical is power consumption. Energy efficiency is a key performance indicator in 5G networks for both User Equipment (UE) and base station side. Numerous power saving techniques are being studied since the initial 5G specifications. Connected mode discontinuous reception (C-DRX) is a power-saving technique in 5G where networks attempt to bring a balance between QoS and power consumption. This paper presents the analysis of C-DRX power saving technique in a laboratory environment and how relevant this feature is, when it comes to save battery power of 5G mobile devices. The results showed that when C-DRX is enabled, the Device Under Test (DUT) battery consumption was 20% lower than when this feature was disabled, considering the DUT in Radio Resource Control (RRC) connected state.**

***Keywords*— C-DRX, Power saving, Power consumption, 5G, ViNR, mobile devices**

I. Introduction

C-DRX techniques allow mobile devices to save energy when they are connected and there is no user data traffic. The discontinuous reception (DRX) feature was first introduced in LTE and the 3GPP Release 16 presented a couple of enhancements to existing techniques applied for 5G networks [1].

Mobile devices such as smartphones, are generally limited in size, being powered by a battery with a capacity limited by the size of the equipment itself [2]. With the adoption of 5G networks, a series of applications and services were introduced and improved for these devices, such as voice and video calls with more quality, games, high-definition video streaming and higher data transfers [2]. To meet the demands of such applications with good quality of service (QoS), the use of advanced signal processing techniques and high bandwidth in NR networks is essential [3]. This demands increase UEs performance as well as the power consumption, draining more battery power from 5G devices [2].

When compared to the great evolution in the semiconductor industry, the evolution of batteries during the last decade has provided an insignificant improvement in the energy density of mobile devices, therefore energy saving methods such as C-DRX are crucial to extend the use of the functionalities of 5G mobile devices [4].

As battery saving optimization has being a determining factor for 5G networks and the future of mobile network, many researches have being performed to improve power saving using 5G networks on both base station and UE side. From base station perspective, the authors in [5] analyzed the power consumption model and introduced four basic power consumption strategies, symbol shutoff, channel shutoff, carrier shutoff and deep sleep. The strategies introduced, showed significant energy-saving gain. In [6], the authors presented power saving techniques and key feature on UE side like Flexible Reference Signal Design for Efficient Sleep Mode, Bandwidth adaptation, DRX mechanism, control channel design for 5G and beyond.

The challenging facet of power saving techniques is about managing to have power saving gain while the performance remain the same or increase. The authors in [7] emphasize radio latency and reliability lost due to a certain 5G new radio power saving feature.

In [8], the authors carried out a research analyzing battery consumption during a video call using Video over LTE (ViLTE) and Video over NR (ViNR), however without enabling C-DRX feature. The authors used Keysight UXM 5G E7515B equipment to generate a simulated network and they compared the battery consumption between ViLTE and ViNR technologies, the experiment was carried out in 3 steps, first, the battery consumption is measured with Airplane mode on for 20 seconds. Next, the airplane mode is turned off and attach procedure is performed for 40 seconds, at the end of the experiment the video call is initiated and last 60 seconds. The results show that UE in idle mode presented more than 20% reduction in consumption on NR networks compared to LTE networks. During the video call, the reduction was more than 7%.

Despite the large number of research regarding power saving in 5G a few of them performed an analysis about C-DRX technique. Therefore diverging from other studies, this research aims to analyze the C-DRX power saving technique in a laboratory environment, thgrouh experiments performed using Rhode&Schwarz CMX500 equipment to generate simulated 5G network, comparing different scenarios with and without

C-DRX feature enabled.

The paper is organized as follows: In Section II, the background on 5G networks, ViNR calls, device power consumption and C-DRX feature are presented. The experimental methodology used in the laboratory employed in this study is outlined in Section III. The data collected in laboratory experiments and results obtained are presented in Section IV. Finally, the conclusion is presented.

II. Background

A. 5G NR Architecture and voice services

The Fifth Generation of Mobile Networks (5G networks), which is being deployed worldwide, has brought with it support for greater connection density, different types of devices, functionalities, and services. The core of the 5G network operates as a Service-Based Architecture (SBA), which in turn is formed by Network Functions (NF's) and Service-Based Interfaces (SBI's). Figure 1 illustrates the main network functions found in the 5G core architecture: Access and Mobility Management Function (AMF), Session Management Function (SMF), User Plane Function (UPF), Policy Control Function (PCF), Unified Data Management (UDM) [9].

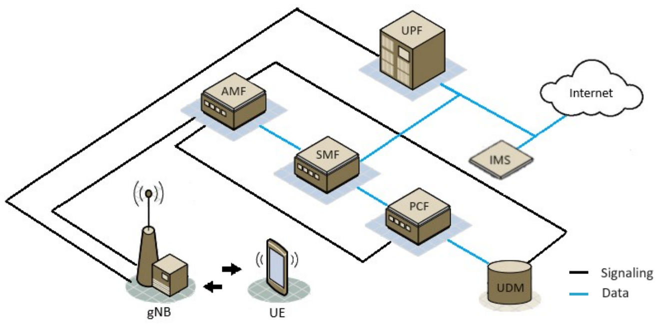

Fig. 1. 5G architecture simplified

AMF is the function responsible for establishing the connection with the Radio Access Network (RAN) and the UE through interface N1. SMF function performs mobile access management on the 5G network, manages sessions by establishing, modifying and updating the Protocol Data Unit (PDU). The UPF include data forwarding and is also responsible for applying QoS considering appropriate usage traffic. PCF is responsible for providing service rules for network functions. These rules are QoS, network access and they can modify the decisions of the UPF, SMF, and AMF. UDM is responsible for managing registers and authorization access to the network as well as user profiles, signatures and authentication [10].

B. Power Consumption/Saving on 5G devices

Energy efficiency is one of the most important aspect about 5G networks deployment. It is challenging to improve user equipment experience in other performance facets without affecting battery life of 5G handsets [6]. As described in [11], energy efficiency measured by bits per Joule is the most widely adopted green design metric for wireless communication systems. Power saving techniques are applied in both UE side and network side. Regarding power saving on UE side, some power saving schemes like DRX [12] mechanism are inherited from 4G LTE. In addition to DRX, other techniques as flexible reference, signal design, efficient sleep modes, bandwidth adaptation, RRC inactive state, control channel design and cross-slot scheduling are also used for power saving in 5G.

C. Connected mode Discontinuous Reception

When there is a data transfer between the UE and the base station with both Signaling Radio Bearer (SRB) and Data Radio Bearer (DRB) active, the UE is in the RRC Connected state. Equivalently, when there is no data transfer between the UE and the base station for a long duration, so both SRB and DRB are released and this state is called RRC Idle state [13]. In RRC Idle state, UE sleep and doesn't listen to any signal from base station, consequently when UE wants to transmit or receive data, the base station has to first change UE's state back to RRC Connected [13]. This change occurs through base station sending a paging signal to UE, but since UE in RRC idle state sleeps and is unreachable, UE has to wake up periodically, stay awake for a small duration and go back to sleep to monitor paging signal. The cycle of UE staying awake and going to sleep periodically is called DRX [12]. The awake and sleep states are called DRX active and DRX inactive respectively. When the previous cycle takes place in RRC connected state, it named Connected mode Discontinuous Reception also known as C-DRX. After a specified duration called Inactivity timer UE enters in C-DRX mode [14]. C-DRX operation has two mode, short DRX and long DRX. Short DRX has a smaller sleep time than long DRX and consequently save less energy.

III. Methodology

A. Experimental Environment

The experiment in this work was conducted in a controlled telecommunications laboratory environment, inside of a shield room to avoid interference from external sources. The equipment used for this research was the CMX500 5G one-box signaling tester, a radio communication tester solution developed by Rhode&Schwarz. This instrument is used to reproduced 4G and 5G network environments, as well as other services like the IP Multimedia Subsystem (IMS) network, which is a feature to provide multimedia communication services for mobile devices, allowing the creation of different test scenarios. The Power monitor (HMC804) was used to measure battery consumption. The measurements from the Power Monitor are generated as a sequence of data and can be exported using a removable disk and then visualized through a computer. Both CMX500 and Power monitor equipment are connected to the DUT, the figure 2 shows the configuration of the equipment used.

The CMX500 5G test equipment established communication with the DUT's RF antennas through conductive cables, and the Power monitor is connected directly to the USB-C input using a specific charging cable. For our experiment,

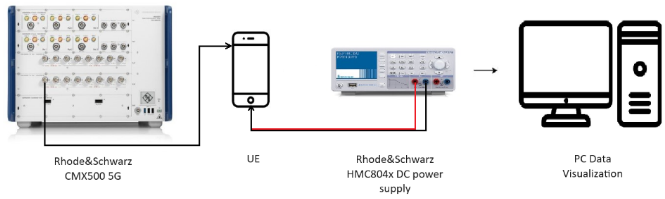

Fig. 2. Setup Configuration

seventeen thousand data points were set. The technical specifications of the DUT used in the experiment are described in Table I.

TABLE I
DUT TECHNICAL SPECIFICATIONS

DUT Components	Hardware Specifications
Chipset	Snapdragon 8 Gen 3
Modem-RF	Snapdragon X70
Baterry	5000mAH
Operating System	Android 14, One UI 6.1

B. Experimental Scenario

Table II shows the network parameters configured on the equipment for our experiment. The 5G band used was n78 with 100MHz as bandwidth, the frequency used was 3500Mhz, and -80dBm as the cell power level (RSRP).

TABLE II
NETWORK PARAMETERS

Network Parameters	5G Cell
Band	n78
BandWidth (BW)	100MHz
Frequency	3500MHz
Power Tx	-80dBm
SCS	30KHz

To analyze the battery consumption behavior of the device, it was necessary to carry out the bypass charging procedure with the DUT connected to the DC power monitor. This procedure allows the device to ignore its original battery and start using power supply only from the DC power monitor. The experiment was divided into a cycle with 4 steps, described below:

- Step 1 (Power off) - Simulate the power-off state on the device via airplane mode activated for 20 seconds;
- Step 2 (RRC connected 1) - After disabling airplane mode, the device performs attach procedure in 5G and then IMS network, this trigger the RRC Connected state, remaining in this state during 40 seconds;
- Step 3 (Video Call) - In step 3, a ViNR call is performed, starting with the call setup procedure, till establishes the video call. DUT remains with the ViNR ongoing for 50 seconds;
- Step 4 (RRC connected 2) - In step 4, the video call is terminated, and the device returns to only RRC Connected state for 60 seconds.

The total time for each measurement procedure was 170 seconds, where the experiment was conducted with C-DRX enabled and then with C-DRX disabled, the difference in power consumption mainly occurs in steps 2 and 4 due to C-DRX feature. Check in the Table III the C-DRX parameters configured in DUT for the experiments.

TABLE III
C-DRX PARAMETERS

C-DRX Parameters	Values
On Duration Timer	6 ms
Inactivity Timer	1280 ms
Harq RTT Timer (DL/UL)	56 symbols
Retrasmission Timer (DL/UL)	16 slots
Long DRX Cycle	10240 ms
Start Offset	0 ms

During the experiments, the current consumption were collected for each one of the 4 steps described, first using C-DRX feature enabled and then using C-DRX disabled. The current value increases a lot when each step is triggered in DUT, for example when the device is registering on network or starting a video call. Therefore, to obtain the mean current consumption values considering only the performance of C-DRX technique, we excluded from the calculations the peak current values obtained during the beginning of each step. Check below the time instants considered for calculating the mean values:

- Step 1 (Power off) - From the second 0 to 19;
- Step 2 (RRC connected 1) - From the second 26 to 60;
- Step 3 (Video Call) - From the second 72 to 109;
- Step 4 (RRC connected 2) - From the second 117 to 170.

IV. RESULTS AND DISCUSSION

This section presents the results collected using the methodology described previously. Two essays of power measurement have been performed with C-DRX disabled and enabled respectively. The graph of Figure 3 displays the difference of power consumption for the same UE when C-DRX is enable and disable.

The major difference occurs in steps 2 and 4, where C-DRX acts. In both steps, the device is in RRC connected mode, i.e. connected to the network without performing any other action. This difference is due to the fact that there was no constant signaling activities during these RRC Connected mode, so after a short period of inactivity the DUT enters in sleep mode to save energy when C-DRX is enable. The Table IV shows the average current values in the different steps. To calculate the measurement mean values obtained in each step, the peak values at the beginning of each stage were disregarded.

With C-DRX enabled, the DUT consumed 23.9% less energy than when C-DRX is disabled in the state of RRC Connected 1 and 26.5% less energy in RRC Connected 2. Despite the fact that ViNR call occurred in the RRC connected mode, the power consumption for C-DRX enabled and disabled mode

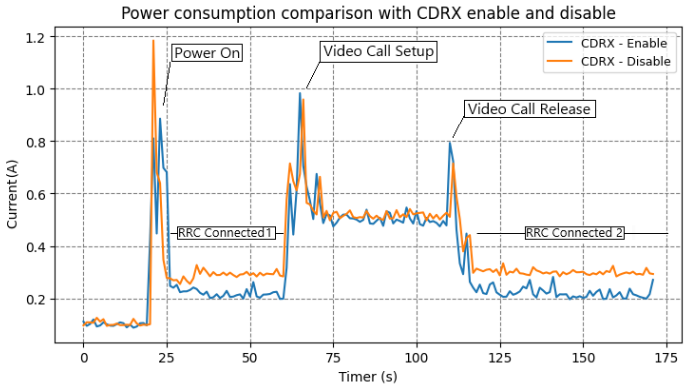

Fig. 3. Power consumption comparison with C-DRX enable and disable

TABLE IV
MEAN CURRENT FOR C-DRX ENABLED AND DISABLED

Procedure	Mean (Enabled)	Mean (Disabled)
Power Off	100.7 (mA)	104.6 (mA)
RRC Connected 1	219.9 (mA)	289.0 (mA)
Video Call	500.6 (mA)	516.6 (mA)
RRC Connected 2	220.5 (mA)	300.0 (mA)

is quit similar, this is justified by the fact during ViNR call there is constant signaling activity, and C-DRX is activated after a short period of inactivity in the RRC connected mode. Since there is no inactivity period while performing ViNR call the DUT couldn't enter in sleep mode when C-DRX is enable that is why there is no variation of power consumption in step 3 comparing to step 2 and 4.

The figures 4 and 5 show the results of the measured current values through statistical boxplot and violin graphs, to analyze the distribution, symmetry, concentration and dispersion obtained.

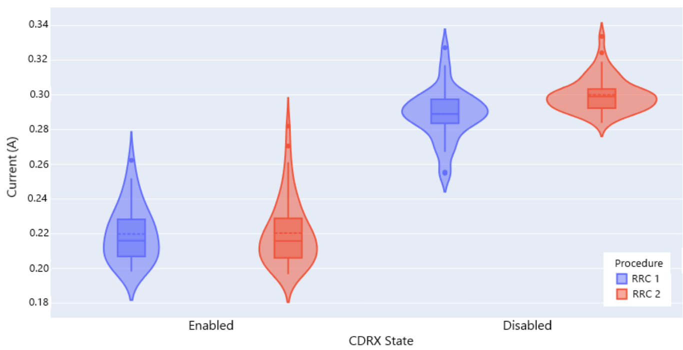

Fig. 4. Comparison with C-DRX enable and disable to RRC 1 and RRC 2 states

Analyzing the graphs with C-DRX enabled for the RRC1 (blue color) and RRC2 (red color) states in figure 4, both RRC1 and RRC2 density curves and boxplot are very similar and they both shown a median current value equal to 216 mA, mean value next to 220 mA (219.9 mA for RRC1 and 220.5 mA for RRC2) and standard deviation (σ) equal to 0.016 for RRC1 and 0.019 for RRC2. It can be observed that the 1st quartile (Q1) has a current value of 206 mA, which represents that 25% of the data are below this value, and the 3rd quartile (Q3) has 228 mA, which represents that 25% of the data are higher than this value both for RRC1 and RRC2 steps with C-DRX enable.

Regarding the graphs with C-DRX disabled for the RRC1 and RRC2 states in figure 4, the density curves shown that all measured current values are well above when compared to the results obtained using the enabled C-DRX. The median current value obtained is 288 mA for RRC1 and 299 mA for RRC2, the mean value is 289 mA for RRC1 and 300 mA for RRC2 and σ is equal to 0.015 for RRC1 and 0.010 for RRC2.

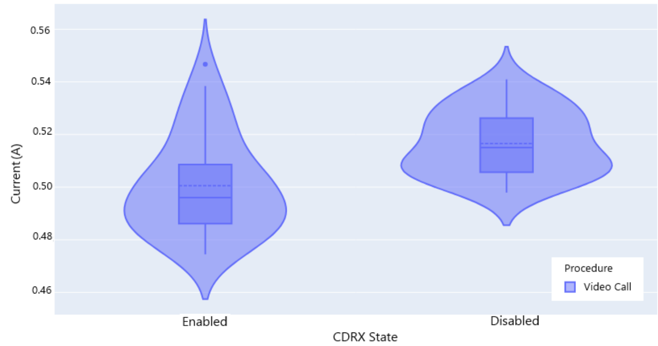

Fig. 5. Comparison with C-DRX enable and disable to Video call procedure

It is notable that the C-DRX feature does not bring any improvement during the video call procedure, which is expected according to the specifications established by 3GPP standards, since this C-DRX operates when there is no constant signalling in RRC connected state.

V. CONCLUSIONS

The evolution of mobile network technologies more specifically 5G use cases introduced concerns about energy consumption. This work presented a study of the battery consumption behavior of a commercial mobile device analyzing C-DRX feature in two scenarios: the first with inactive C-DRX and the second with active C-DRX, both attached to the 5G network in a controlled laboratory environment.

The results of the experiment confirm the reduction of power consumption when the mobile device is attached to the 5G network in RRC connected state and C-DRX active, the approximate average value of consumption in the RRC Connected 1 was 219.9 mA and in the RRC Connected 2 was 220.5 mA, both with C-DRX activated. While for C-DRX disabled, this values were approximately 289 mA for RRC1 step and 300 mA for the RRC2 step, which brings a reduction of 23.9% and 26.5% for RRC1 and RRC2, respectively. The consumption pattern showed very similar values in the step 1, when there is no signaling activity and when constant signaling activity is performed respectively, as well as in the Step 3, when a video call was established.

The boxplots and violin ghraps in figure 4 shown that density curves are very similar for both RRC1 and RRC2 steps. The RRC connected states with C-DRX feature activated brings lower values for measured current values. Nevertheless, analyzing the graphs of video calls in figure 5 with C-DRX enabled and disabled, the density curves shown that they are many convergent data points, with the data of C-DRX enabled values containing more dispersed data, but not so different than the values obtained with C-DRX disabled.

C-DRX doesn't interfere only in power saving, there is a close relationship between C-DRX and latency. Since the mobile device enter periodically in a sleep mode in RRC connected state when there is no signalling traffic, the latency can be higher when C-DRX is activated. In futures works an analysis can be performed to study how C-DRX can impact directly the network latency.

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