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Power Consumption Modeling of 5G Millimeter-Wave User Equipment

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Abstract

The deployment of the 5th generation mobile network (5G) on the network side has been widespread in many countries for several years. There is demand for enhanced mobile broadband (eMBB), low latency, and high energy efficiency in both user equipment (UE) and base station sides of 5G networks. In this study, the power consumption models of 5G milimeter-wave (mmWave) UE are examined. Non-standalone (NSA) is utilized in the test setup, with LTE band 5 serving as an anchor cell in the master cell group (MCG), and the new radio (NR) cell serves for dual connectivity in a secondary cell group (SCG).

(Methodology, results and conclusion here ...)

Acknowledgments

To be added..

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Notation

Notation

Notation	Meaning
–	to be added

Abbreviations

Shortening	Meaning
3GPP	3rd Generation Partnership Project
5G	5th Generation Mobile Network
5GCN	5G Core Network
BWP	Bandwidth part
CA	Carrier Aggregation
CRS	Cell-specific Reference Signal
CSI-RS	Channel State Information Reference Signal
DL	Downlink
DMRS	Demodulation Reference Signal
DRX	Discontinuous Reception
EE	Energy Efficiency
eMBB	Enhanced Mobile Broadband
EN-DC	Eutra-NR Dual Connectivity
FR2	Frequency Range 2
GUI	Graphic User Interface
LNA	Low Noise Amplifier
LTE	Long Term Evolution
MCG	Master Cell Group
MCS	Modulation Coding Scheme
NR	New Radio
OFDM	Orthogonal Frequency Division Modulation
PA	Power Amplifier
PBCH	Physical Broadcast Channel
PSDCH	Physical Downlink Shared Channel
PSS	Primary Synchronization Signal
SCG	Secondary Cell Group
SSB	Synchronization Signal Blocks
SSS	Secondary Synchronization Signal
UE	User Equipment
URLLC	Ultra-reliable Low-latency Communication

1 Introduction

The technical specifications of the UE have continually evolved to become more computationally powerful every year. It is also expected to perform well in both throughput and latency as these factors are closely linked to power consumption in the UE. There are always trade-offs between latency, throughput, and energy efficiency in the UE. This thesis will primarily focus on discussing the power consumption of the cellular modem while disregarding power consumption in other components such as the processing unit, background applications, screen etc.

Long Term Evolution (LTE) has undergone a long journey of development since its first specification, Release 8, in 2009, and has reached maturity over time. First 5G specification, on the other hand, was released in 2017, Release 15, while LTE continues to be developed in parallel with 5G, as it remains an important component of 5G NSA. While there are multiple solutions for 5G, also known as NR, this thesis will focus on 5G NSA option 3a, as shown in Fig.1.1, for network-side setup. NSA option 3a has been widely deployed in the transition period toward 5G because it is fast in implementation with legacy Evolved Packet Core (EPC) so less capital in investment of 5G Core Network (5GCN). Moreover, NSA is widely used because dual connectivity provides larger coverage using sub-6 GHz of LTE and a wider bandwidth capacity in Frequency Range 2 (FR2) in NR [2]. This chapter includes an introduction to 5G design from the perspective of energy efficiency, power consumption features by 3GPP, and the scope of this thesis work.

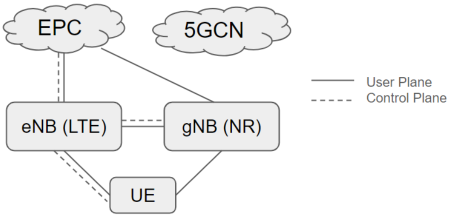

Figure 1.1: *NSA option 3a network topology.*

1.1 5G design in energy efficiency view

In 5G, the demodulation reference signal (DMRS) in the channel state information reference signal (CSI-RS) for decoding physical downlink shared channel (PDSCH) does not transmit when there isn't data to transmit, unlike the always-on cell-specific reference signal (CRS) in LTE, which is constantly transmitted, causing more power consumption [2]. The CSI-RS was introduced in LTE in Release 10 to support 8-layer multiplexing and mitigate signaling overhead in extending CRS, so 5G development is inspired by LTE. In 5G, the bandwidth can be up to 400 MHz per carrier frequency, so bandwidth part (BWP) is introduced to ensure that the UE only utilizes a set of consecutive resource blocks and doesn't need to receive the entire carrier bandwidth.

The scalable orthogonal frequency division multiplexing (OFDM) numerology of sub-carrier spacing of $15x2^n$ kHz, where n is an integer between 0 and 4 causes variation in slot, symbol and cyclic prefix duration, unlike in LTE where sub-carrier spacing is fixed at 15 KHz. This flexibility allows for wider sub-carrier spacing to be utilized in higher carrier frequencies, such as FR2, enabling the use of larger carrier bandwidth or for ultra-reliable low-latency communication (URLLC) services, due to their shorter symbol duration. Conversely, shorter sub-carrier spacing can be used in lower carrier frequencies, which provide broader coverage.

In initial access in NR, base station transmits synchronization signal blocks (SSB) in downlink direction that contain primary synchronization signal (PSS), secondary synchronization signal (SSS) and physical broadcast channel (PBCH) and they function for initial access and beam sweeping. SSB signals are spread over 20 resource blocks, 240 subcarrier, in frequency domain and inside 5 ms in every 20 ms while it is transmitted every 5 ms in LTE. The sparse SSB raster in the frequency domain is supported in NR, so that the UE doesn't need to search all possible frequency-domain positions, especially the frequency range is quite large in FR2. The larger periodicity in time will improve energy efficiency on the network side, particularly for the base station.

In some communications, such as URLLC, energy efficiency is less of a priority in order to facilitate the service. Thus, slots can be scheduled even if the symbols have not yet been completely filled in the slots. They are called mini-slots.

Aforementioned designs have a direct impact on energy efficiency both UE and network sides. However, in this thesis, UE-side power consumption is primarily focused. It can be said that the design of NR is lean, flexible, and scalable. Moreover, the forward compatibility of NR provides opportunities for future development of new solutions.

1.2 3GPP features toward UE energy efficiency

A technical report by 3GPP shows about the study of UE power saving schemes [1]. There are schemes of adaption in variation in frequency and time, number of antenna and discontinuous reception (DRX) operation. Schemes about adapting and relaxing radio resource management (RRM) measurements. An introduction to RRC_INACTIVE mode that act like an idle mode with established of radio resource control (RRC) context and core-network (CN) connection. The RRC_INACTIVE state will reduce overhead in states transition between RRC_CONNECTED and RRC_IDLE.

1.3 Previous studies about power consumption and energy efficiencies in UE

There were studies about UE power modeling. A study shows that the model can be divided in two part: baseband power and radio frequency (RF) power. It is found that uplink (UL) and downlink (DL) transmitted power and modulation scheme index (MCS) are closely linked to the UE power consumption [4], hence they are used in the power consumption models. The factor in UE transmission power in uplink direction, representing power consumption in the power amplifier (PA), and the factor in UE reception power in downlink direction, representing power consumption in the low-noise amplifier (LNA).

A study shows that there is an improvement of roughly 38 percent in energy efficiency (EE) in transition between 1st and 2nd generation UE, that were made in 2012 and 2013 respectively [5]. The EE it the unit of energy that is used to transfer one byte of data. In addition, an increased throughput in factor of 10 will increase power by 10 percent [5].

A study about power consumption in carrier aggregation (CA) in LTE-Advance shows that CA improves power saving by 31 percent when the throughput is doubled and the file for transmission is large [3]. File size matters here because the higher throughput can quickly finish transmission and turn UE into sleep mode.

1.4 Scope in the thesis

In this thesis, the primary focus is on UE power consumption modeling. The UE will be set up with a radio network emulator to perform multiple parameter measurements. The cases are prepared and will be collected for modeling. The models are derived by applying different methods to model and compare their performance.

2

Test and Environment Setup

Due to the popularity of NSA deployment of 5G, the legacy LTE in lower frequencies is used as an anchor to provide wide coverage, while NR possibly in higher frequencies, specifically FR2, is utilized to boost throughput in dense areas. In this thesis, 5G NSA with LTE and NR dual connectivity, known as ENDC, is selected, using 10 MHz of band b5 in LTE and 100 MHz of band n260 in NR.

2.1 Radio network emulator and chamber setup

The radio network emulator R&S CMX500 Radio Communication Tester is used for generating the signal in network side in the lab as in Fig.2.1. There are 2 ports dedicated for NR band 260, one for horizontal and another one for vertical polarization. The same apply to band 5 of LTE one for main polarization and one for diversity polarization.

Figure 2.1: *R&S CMX500 Radio Communication.*

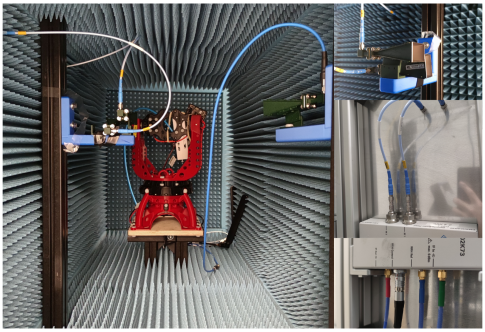

Figure 2.2: *Clockwise: the chamber, horn antennas, and RF ports.*

The RF feeder is connected from the CMX500 to the horn antennas inside the chamber as in Fig. 2.2. The UE is mounted in the electrical controllable gimbal which is stationary and programmable for different orientation in both horizontal and vertical direction. The whole setup is presented in the diagram in Fig 2.3.

The graphic user interface (GUI) of the radio network emulator is shown in Fig. 2.4

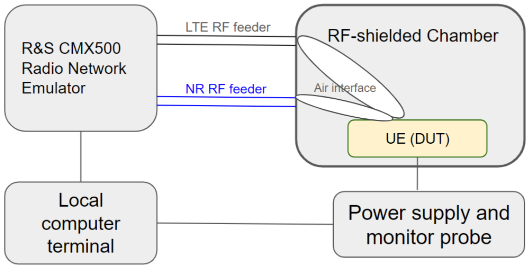

Figure 2.3: *Test setup diagram*

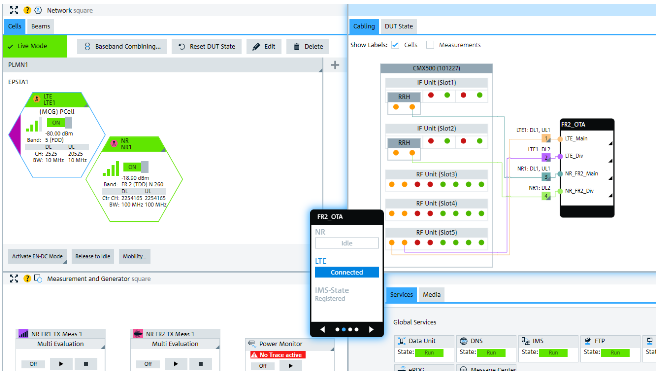

Figure 2.4: *GUI of radio emulator.*

2.2 Controlable Gimbal

The gimbal is used to control position of UE so that UE can have different channel quality. It can also be used for the case that UE need to sweep around the different direction in horizontal or vertical orientation to measure the channel quality of all 360 degrees.

2.3 Network-side baseline parameters

Baseline parameters is the set of values in the configuration of the radio network emulator. These include radio parameters, timer parameters, feature parameters, etc. Test schemes is the specific setting of part of the parameters to learn behavior of the UE power consumption according to each scheme.

3

Measurements and Data Collection

3.1 Baseline parameters

The baseline parameters are the set of parameter that is used as a based in all test cases as in the table 3.1.

3.2 LTE-only baseline

3.3 ENDC baseline

3.4 LTE-only horizontal sweeping

3.5 ENDC horizontal sweeping

3.6 NR UE tx power sweeping (UL trasmission power

3.7 NR Cell tx power sweeping (DL transmission power)

3.8 NR carrier bandwidth position in band n260

3.9 NR in different carrier bandwidth

Table 3.1: Baseline parameters

LTE parameters	NR parameters
Frequency Frequency band indicator: 5 Frequency bandwidth: 10 MHz EARFCN DL: 2525 EARFCN UL: 20525 Carrier Frequency DL: 881.5 MHz Carrier Frequency UL: 836.5 MHz	 - - - - - -
Power downlink Max Cell Power: -52.2 dBm Reference Signal Power: 15 dBm **Power uplnk** TCP: Closed loop Target Power Total RMS: 0 dBm	 - - - -
- -	 -
- -	 -
- -	 -

4 Modeling

to be added ...

5

Models Evaluation

to be added ...

6

Conclusion

Conclusion

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Index

BWP
abbreviation, x

CA
abbreviation, x
CRS
abbreviation, x
CSI-RS
abbreviation, x

DL
abbreviation, x
DMRS
abbreviation, x
DRX
abbreviation, x

EE
abbreviation, x
EMBB
abbreviation, x
EN-DC
abbreviation, x

5G
abbreviation, x
5GCN
abbreviation, x
FR2
abbreviation, x

GUI
abbreviation, x

LNA
abbreviation, x
LTE
abbreviation, x

MCG
abbreviation, x
MCS
abbreviation, x

NR
abbreviation, x

OFDM
abbreviation, x

PA
abbreviation, x
PBCH
abbreviation, x
PSDCH
abbreviation, x
PSS
abbreviation, x

SCG
abbreviation, x
SSB
abbreviation, x
SSS
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3GPP
abbreviation, x

UE

abbreviation, x
URLLC
abbreviation, x