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Towards Radio Access Network intelligence in mobile communication systems beyond 5G

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by
Marta Samper Mota

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Advisor: Anna Umbert

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Abstract

This final degree thesis is part of a project of the Mobile Communications Research Group (GRCM) of the Polytechnic University of Catalonia. The project is focused on the development of operations and management mechanisms and algorithms that with the use of artificial intelligence and machine learning in the 5G era and the next generations, integrate user equipment as part of the intelligence of the end-to-end connected network. This would materialise data analytics solutions that would not need to expose the network to a large amount of raw data collected by UEs.

In this context, the aim of this thesis is to create a local network in order to test the different algorithms that lead to the intelligence of the radio access network in an environment beyond 5G. This includes configuring and analysing the performance of the assembled network as well as understanding the operation of each of its component parts.

Resum

Aquesta tesi de final de grau forma part d'un projecte del Grup de Recerca en Comunicacions Mòbils (GRCM) de la Universitat Politècnica de Catalunya. El projecte està enfocat al desenvolupament de mecanismes i algoritmes d'operació i gestió que amb l'ús de la intel·ligència artificial i l'aprenentatge autònom a l'era del 5G i les següents generacions, integri els equips d'usuari com a part de la intel·ligència de la xarxa connectada d'extrem a extrem. D'aquesta manera es materialitzaria solucions d'anàlisis de dades que no necessitarien exposar a la xarxa a una gran quantitat de dades recopilades en brut pels equips d'usuari.

En aquest context, l'objectiu d'aquesta tesis es crear una xarxa local per a poder testejar els diferents algoritmes que portin a la intel·ligència de la xarxa d'accés en un entorn més enllà del 5G. Això inclou configurar i analitzar les prestacions de la xarxa muntada a més d'entendre el funcionament de cadascuna de les parts que la componen.

Resumen

Esta tesis de final de grado forma parte de un proyecto del Grupo de Investigación en Comunicaciones Móviles (GRCM) de la Universidad Politécnica de Cataluña. El proyecto está enfocado al desarrollo de mecanismos y algoritmos de mantenimiento y gestión que con el uso de la inteligencia artificial y el aprendizaje autónomo en la era del 5G y las siguientes generaciones, integre los equipos de usuario como parte de la inteligencia de la red conectada de extremo a extremo. De esta manera se materializaría soluciones de análisis de datos que no necesitarían exponer a la red a una gran cantidad de datos recopiladas en bruto por los equipos de usuario.

En este contexto, el objetivo de esta tesis es crear una red local para poder testear los diferentes algoritmos que lleven a la inteligencia de la red de acceso en un entorno más allá del 5G. Esto incluye configurar y analizar las prestaciones de la red montada además de entender el funcionamiento de cada una de las partes que la componen.

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Name	e-mail
Marta Samper	marta.samper@estudiantat.upc.edu
Anna Umbert	anna.umbert@upc.edu

Written by:		Reviewed and approved by:	
Date	10/05/2022	Date	07/06/2022
Name	Marta Samper	Name	Anna Umbert
Position	Project Author	Position	Project Supervisor

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1 Introduction

1.1 Statement of purpose

The infrastructure of mobile networks has been constantly expanding and improving with new technologies to the point where it has already become the largest technology platform in human history. Radio Access Network (RAN) equipments make up a large part of this infrastructure, with millions of base stations with macro, micro and small cells deployed around the world.

Likewise, from the user equipment (UE), we have also witnessed an unprecedented technological evolution that leads to UEs with very powerful and advanced communication and computing capabilities. This is visible both in the form of personal devices, such as high-end smartphones and wearables, and in the form of equipment integrated with other platforms or systems such as cars and drones. These huge advances in UE capabilities have reached the point where the original functional disparity between UE (simple) and RAN (sophisticated) equipments is blurring.

In addition, in view of the widespread exploitation of Artificial Intelligence (AI) and machine learning (ML) in the 5G era and beyond, UE integration as part of end-to-end connected network intelligence is a cornerstone for the realization of real-context awareness and fully distributed data analysis solutions that do not need to expose the large amount of raw data to the network compiled by the UEs.

The purpose of this project is to set up a mobile local network to be able to do demonstrations. Once the networks is up and running, tests will be carried out aiming to test solutions in an environment beyond 5G, in order to contribute to developing the intelligence of the mobile communications network.

The project main goals are:

- 1.- Set up a local network for demonstrations.
- 2.- Understand the functioning of each of the parts that make up the network.
- 3.- Configure the different use cases available on the network.
- 4.- Analyzing performance.

1.2 Requirements and specifications

The necessary requirements to carry out this project are:

- A computer where the srsRAN software can be installed along with the necessary drivers to operate the hardware.
- USRP equipment to be able to transmit the signals.
- Antennas to be able to transmit.
- Mobile phone that can operate with a programmable USIM.
- A programmable USIM.

1.3 Methods and procedures

At the beginning of the project it was necessary to become familiar with the operation and terminology of the LTE system, while at the same time following the instructions to install the srsRAN software and learn how to use it.

Prior research made it possible to understand each part of the code and configuration files. In order to get the network up and running, it was necessary to make changes to the configuration files and check with the mobile phone that it worked. Finally, with the local LTE network up, it was time to analyse the performance by testing different configurations, and finally to create a user manual for when, in the future, algorithms or mechanisms need to be tested with this platform.

1.4 Working plan

The tasks to be carried out in this project are divided into 3 work packages:

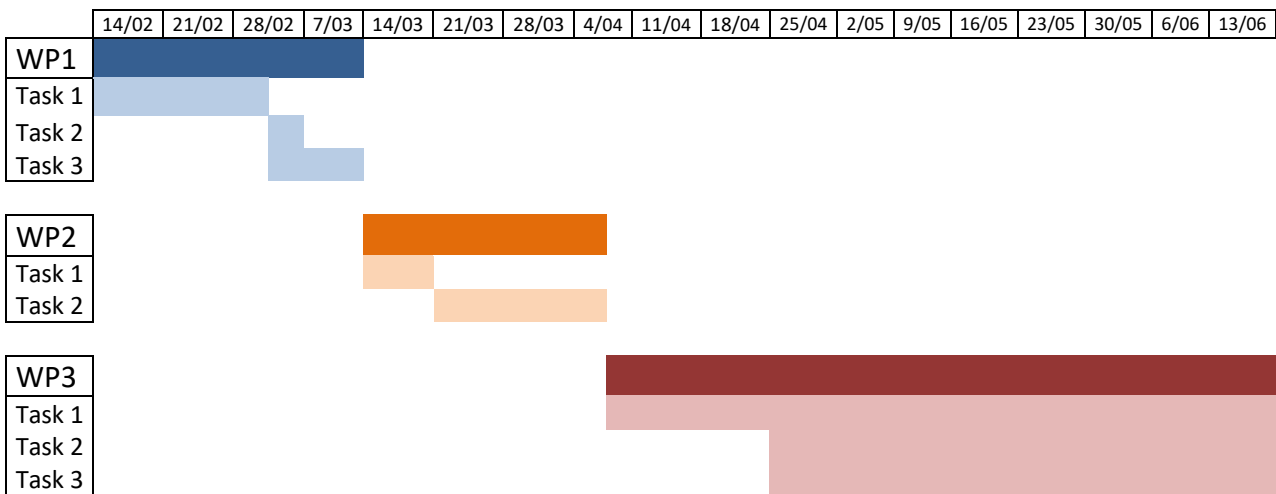
WP1	Research	
	Start Date	Finish Date
Install srsRAN and the drivers needed in both machines.	14/02/2022	3/03/2022
Install srsGUI.	3/03/2022	4/03/2022
Install PySim.	7/03/2022	14/03/2022

WP2	Research	
	Start Date	Finish Date
Program Sim Card for the UE.	14/03/2022	18/03/2022
Connect the UE to the eNB.	21/03/2022	6/04/2022

WP3	Research	
	Start Date	Finish Date
Do some testing on that network.	6/04/2022	17/06/2022
Document testing.	25/04/2022	17/06/2022
Program structure.	25/04/2022	17/06/2022

WP#	Task#	Short title	Milestone / deliverable	Date (week)
1	1	srsRAN	srsRAN running in two machines.	14/02 - 28/02
1	2	srsGUI	Correct compilation and pass all the tests.	03/03
1	3	PySim	Read the sim card connected.	03/03 - 7/03
2	1	Program Sim	Insert the desired parameters.	14/03 - 16/03
2	2	Network	See the transmitted information on the EPC.	16/03 - 6/04

3	1	Tests	Obtained the estimated values for an LTE network.	6/04 - 13/05
3	2	Document	Write and compare the results obtained.	20/04 - 16/05
3	3	Structure	Study the program structure and identify the different components that make up an LTE network	20/04 - 16/05



1.5 Deviations from the original plan

The original plan was to set up one computer to host the srsEPC and srsENB and on another computer to host the srsUE, each with a different USRP connected.

The material available in the laboratory from the beginning were the computers and 1 USRP, which is why the second USRP was purchased. Due to problems with the supply of electrical components, the delivery time, which was initially 60 days, was extended until it became impossible to use it in this thesis, so we analyse the network only with the smartphone.

2 State of the art of the technology used or applied in this thesis

2.1 5G

5G is the 5th generation mobile network. It is meant to deliver higher multi-Gbps peak data speeds, ultra low latency, more reliability, massive network capacity, increased availability, and a more uniform experience to more users. Broadly speaking, it is used across three main types of connected services, including enhanced mobile broadband, mission-critical communications and massive IoT (Internet of Things). A defining capability of 5G is that it is designed for forward compatibility—the ability to flexibly support future services that are unknown today. The 5G technology is OFDM-based (Orthogonal Frequency-Division Multiplexing) and will operate based on the same principles as 4G mobile network [1].

There are currently two modes deployed [2]:

- NSA (Non-standalone) mode
The NSA mode of 5G NR (New Radio) deployment depends on the control plane of an existing 4G LTE (Long Term Evolution) network for control functions, while 5G NR is exclusively focused on the user plane.
- SA (Standalone) mode
The SA mode of 5G NR refers to using 5G cells for both signalling and information transfer. It includes the new 5G Packet Core architecture instead of relying on the 4G Evolved Packet Core, to allow the deployment of 5G without the LTE network. However, initial deployment might be slower due to the cost to deploy new infrastructure versus using existing infrastructure.

Nowadays only the 10% of the operators offering 5G are doing so with 5G SA, the one that is being deployed in most of the world is the 5G NSA. For this reason, it is necessary to know and understand how an LTE network works.

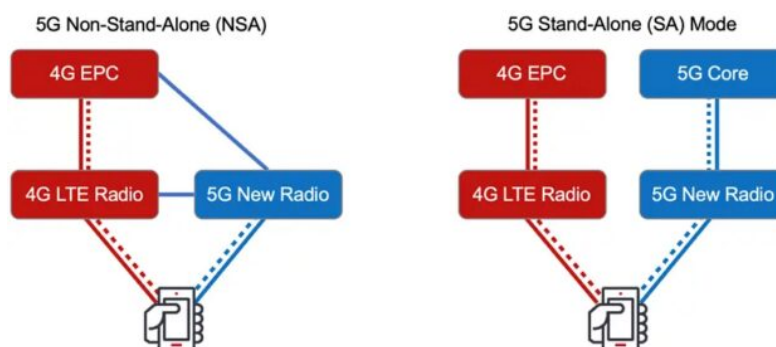


Figure 1. 5G modes

2.2 LTE system fundamentals

The term LTE was initially adopted by the 3GPP organization to refer to the evolution of the UMTS (Universal Mobile Telecommunications System) whose Radio Access Network (RAN) is called UTRAN (UMTS Terrestrial Access Network). The new access network is called E-UTRAN (Evolved UTRAN), it consists of a single element called eNB (evolved NodeB) which constitutes the base station integrating all the functionality of the radio access network [3].

The architecture of a cellular mobile communications system, represented in Figure 2, consists of three components [3]:

- User Equipment (UE), device that allows the user to access the network services.
- Access Network, part of the system that manages the radio transmission with the UEs to provide the necessary connectivity between the UE and the core network.
- Core Network (CN), part of the system that manages things like the authentication of system users, user mobility management, management of data sessions, data routing (paging), databases, etc.

The separation between the core network and the access network gives the system greater flexibility to upgrade, add and replace different parts of the network with minimal impact on the rest of the network.

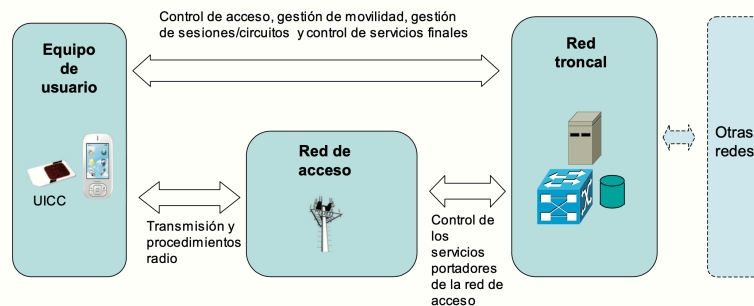


Figure 2. Generic architecture of a cellular system

In particular, the architecture that has the LTE system consist of the access network E-UTRAN and the EPC packet domain of the core network (hereinafter referred to as EPC CN). They jointly provide services for the IP packet transfer between users equipment and external packet networks such as the Internet.

On one hand, as can be seen in the Figure 3, the interface that links E-UTRAN and EPC is called S1 and provides the necessary mechanism to manage the access of mobile terminals through the E-UTRAN. The radio interface between the E-UTRAN and the UEs is called E-UTRAN U_i. On the other hand, the IMS (IP Multimedia Subsystem) service platform and the connections to external IP packet networks is carried out via the interface SGi of the EPC. The control mechanism for the transport services offered by the EPC are provided by other CN elements that are not unique to the LTE system. This forms the main skeleton of an LTE system, below the main components will be explained with a little more detail [3].

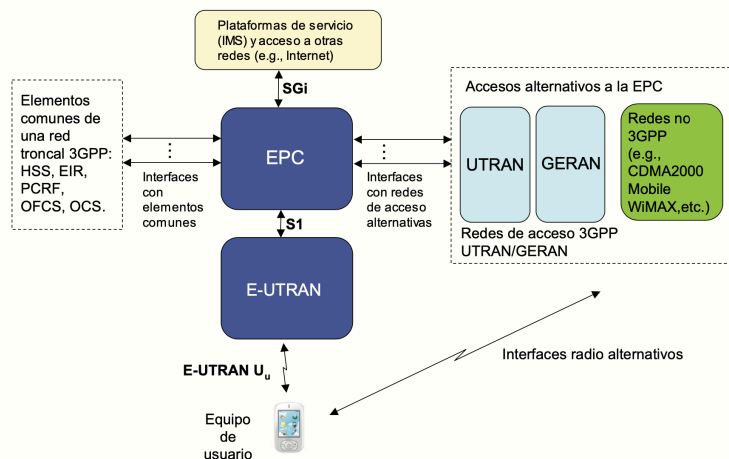


Figure 3. LTE system architecture

2.3 Evolved Packet Core (EPC)

The EPC core network design is primarily intended to provide an IP (Internet Protocol) connectivity service and the reason for that is that the 3GPP community decided to use IP as the key protocol to transport all services.

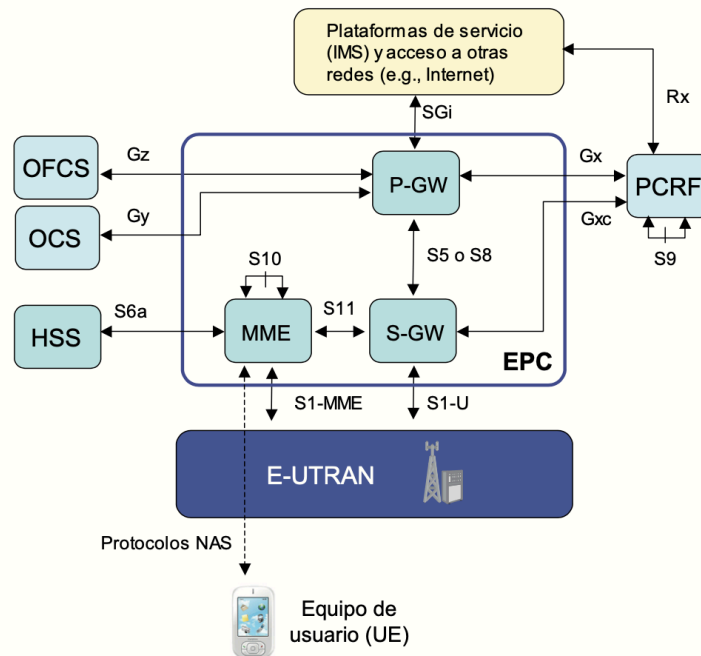


Figure 4. Basic architecture of the EPC core network

The basic elements for the provision of the IP connectivity service between user equipment connected via E-UTRAN and other external networks are as follows [3]:

Mobility Management Entity (MME)

All terminals that are registered in the LTE network accessing through E-UTRAN, have an assigned MME entity. This MME entity will change depending on the user's mobility within the service area. Its tasks are [3]:

- Authentication and authorisation of user access through E-UTRAN based on data obtained from HSS.
- Modify signalling to establish, maintain, modify and release services based on some QoS (Quality of Service) parameters on which the forwarding of IP packets between users and the backbone is based.
- Location of users within the service area in which they are registered in the LTE network. Tracking areas and associated procedures are defined.
- Signalling for mobility support between different services with their QoS parameters and other 3GPP networks (GSM, GPRS, UTRAN, etc.).
- Termination of NAS (Non Access Stratum) signalling protocols between the UE and its assigned MME entity. Through the NAS protocols are endured the access control to the LTE network, the management of external connections and the management of terminals that are in *idle* mode (the UE does not have any control connection established with E-UTRAN).

Serving Gateway (S-GW)

It is the user gateway between E-UTRAN and the EPC core network. Its main functions are [3]:

- Anchor point in the EPC network with respect to UE mobility between eNBs and also between other 3GPP access networks.
- Temporary storage of user IP packets in case terminals go into *idle* mode.
- Routing of user traffic. Although a user is connected to different P-GW gateways each with its downstream traffic simultaneously, the outgoing traffic goes through a single S-GW.

Packet Data Network Gateway (P-GW)

It is responsible for providing connectivity between the LTE network and external networks.

To highlight the next functions [3]:

- Application of the charging control and control policy to the bearer services established by the terminal.
- Assignment of the IP address of a terminal used in a given external network.
- Anchoring for mobility management between LTE and non-3GPP networks.

Home Subscriber Server (HSS)

It is the main database of the 3GPP system that stores the information of the network users. It contains both permanent information that can only be changed through administrative processes (for example, fields created when a user registered in the network or changing the conditions of his/her contract), as well as temporary information that changes as a result of the operation of the system itself (for example, location of the terminal within the service area) [3].

2.4 Evolved Node B (eNB)

The E-UTRAN consist of several eNB connected to each other. All protocols specific to the radio interface are implemented in the access network instead of the core network, that makes the interaction between protocol layers much more efficient. By distributing the control to each eNB, latency is reduced and the need of a centralized controller is avoided [3].

The eNB is responsible for all LTE radio functionality. Each node is in charge of providing service to a coverage area, this coverage area is divided into several sectors known as cells. The most relevant eNB functionality is [3]:

- Radio admission control, is responsible for managing access to the system for new service request based on the required QoS and the conditions of occupation of the available radio resources.
- Mobility control, ensures that the terminals are in the best conditions to communicate with the system and in case of not being able to guarantee it, transfer the communication of a user from one cell to another.
- Power control, it is responsible for determining the transmission power required at any given moment on the different subcarriers assigned to the different users.
- InterCell Interference Coordination (ICIC), mechanism to coordinate transmissions made by neighbouring cell by avoiding simultaneous transmissions on the same radio resource and by controlling transmission power in order to mitigate mutual interference between these cells.
- Packet Scheduling, determines the dynamic allocation of the radio resources to users so that they can carry out their transmissions in an orderly fashion over shared channels.

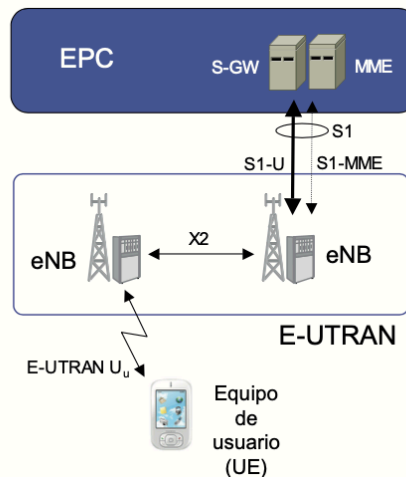


Figure 5. E-UTRAN access network

2.5 User Equipment (UE)

The UE usually is a cell phone or another electronic device that allows users of the LTE system to access the LTE network services via the radio interface. As defined in the standards, it is compound of two basic elements: a user subscription module (SIM/USIM) and the actual mobile equipment (ME). The separation between USIM and ME makes it easier for a user to change the terminal while keeping the user's identity [3].

The ME integrates the functions of communication with the cellular network as well as the additional functions that allow the user to interact with the network services.

The user subscription module is realised through the use of a Universal Integrated Circuit Card (UICC) which contains the application that manages the user subscription data to 3GPP networks. The UICC is the only subscriber-owned component in an LTE network that an operator has no physical control over, but as it is always IP-connected the operators can remotely do changes to the application, for example, changing the roaming agreements [3].

The SIM/USIM is associated with a user and therefore identifies the user in the system regardless of the mobile equipment used. It stores important information as security keys, Mobile Station International Subscriber Directory Number (MSISDN), Mobile Network Code (MNC) and Mobile Country Code (MCC) [3].

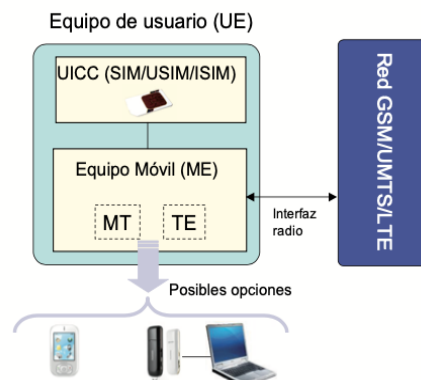


Figure 6. User equipment

2.6 LTE Architecture

LTE systems use multiple protocols for the communication between the UE, the eNB and the EPC. Each protocol performs operations on the control plane and/or the user plane. The user plane is intended for sending user information, IP packets sent between the UE and the S-GW on the EPC. The control plane is intended to transport the control messages between the UE and the MME that allow the correct functioning of the system [3].

As can be seen in Figure 7, the two plans have been depicted, followed by a brief explanation of each protocol and entity/layer.

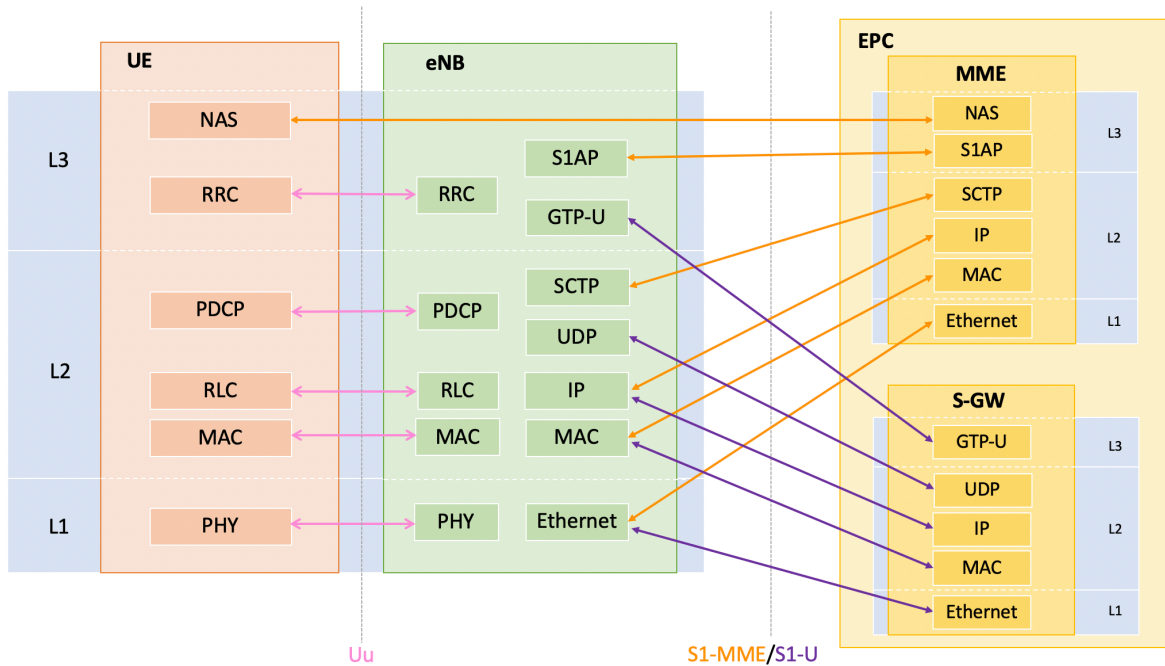


Figure 7. Protocol stack

2.6.1 Protocols

Non-Access Stratum (NAS)

It is supported between the user equipment and an MME node. It performs mobility management of user equipment and session management. In particular, the mechanisms of *Network Attach* (registration), *Detatch* (deregistration) and *Tracking Area Update* are used to control mobility. If the terminals are in idle mode (the terminal has no established radio bearer service), the NAS protocol supports the notice procedure (*paging*) and also allows the network to interrogate the terminal equipment for sending identifiers such as IMSI (International Mobile Subscriber Identity), IMEI (International Mobile Equipment Identity) and to perform user authentication [3].

S1 Application Protocol (S1AP)

The S1AP handles signalling and paging between the E-UTRAN and the EPC. It also transfers NAS signalling between the MME and the UE [4].

GTP-U

The GTP-U provides an encapsulation mechanism for sending user packets between nodes in an IP network via radio bearer services and the S1 [3].

Stream Control Transmission Protocol (SCTP) and User Datagram Protocol (UDP)

The SCTP and the UDP are the protocol utilized as transport for all signalling between the radio access network and the EPC [5].

2.6.2 Sublayers

Radio Resource Control (RRC)

The RRC is in charge of controlling the behaviour of the UE when is connected to an eNB. The main functions of the RRC protocol are [3]:

- Control of the procedures related to the establishment, maintenance and closure of an RRC connection such as establishment of signalling radio carriers and user data radio carriers, initialisation of security and encryption mechanisms, configuration of lower layers, etc.
- The RRC is also responsible for handling and responding to paging messages from the network.
- Information transfer mechanisms in case of mobility.

Packet Data Convergence Protocol (PDCP)

The functions of the PDCP are to carry RRC signalling and user data and cipher it, the protection of the integrity of RRC layer messages and reordering and/or duplicity detection of RLC packets when implementing mobility mechanisms between eNBs [3].

Radio Link Control (RLC)

The RLC sublayer is responsible for reliable transmission of information through the air. In particular [3]:

- Segmentation/concatenation of the IP packets of the upper layers to adapt them to the transmission capacities.
- Retransmission of the new packets created that are received incorrectly and avoid duplicities.

It has 3 different operation modes:

- Transparent Mode (TM) bearers simply pass data through the RLC.
- Unacknowledged Mode (UM) bearers perform concatenation, segmentation and reassembly of data units, reordering and duplication detection.
- Acknowledged Mode (AM) bearers additionally perform retransmission of missing data units and resegmentation.

Medium Access Control (MAC)

The sublayer MAC provides the link between the RLC sublayer services and the physical layer, it has the responsibility to [3]:

- Implement procedures for error correction mechanisms.
- Priority management between logical channels.
- Selection of transmission format (modulation type, transport block size, etc.).
- Multiplexing/demultiplexing of MAC packets.
- Reporting on radio resource management.

Physical (PHY)

The physical layer of the LTE system is based on the use of OFDMA multiple access techniques in the downlink (eNB to UE) and SC-FDMA in the uplink (UE to eNB). In both cases the subcarrier spacing is fixed and equal to 15kHz.

The possible modulation schemes are QPSK, 16 QAM and 64 QAM for downlink and QPSK and 16 QAM for uplink. The PRB (Physical Resource Block) is the smallest piece of information that can be assigned by the eNB to a mobile terminal. One PRB occupies 180 kHz of bandwidth equivalent to 12 sub-carriers spaced 15 kHz apart [3].

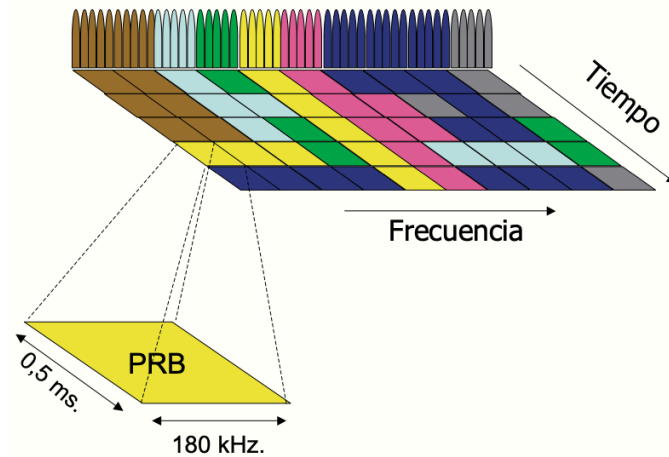


Figure 8. Physical Resource Block concept

As can be seen in the second row of Table 1, the peak rates including both user data and reference signals and signalling channels are indicated. The resources allocated to control and signalling in LTE range around 15% of the total available resources, in the third row of Table 1 you can see some bound for the transmission rates [3].

Channelling	1,4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz
PRB number	6	15	25	50	75	100
Total peak speed (Mbps)	≅ 6	≅ 15	≅ 25	≅ 50	≅ 75	≅ 100
Raw peak user speed (Mbps) (15% of the resources are destined for control and signalling)	≅ 5,1	≅ 12,8	≅ 21	≅ 42,5	≅ 63,7	≅ 85

Table 1. Number of PRBs and possible peak speeds depending on the channelization

In the downlink, LTE uses different ways to transmit [6]:

- TM 1 – Single transmit antenna
This mode uses only one transmit antenna.
- TM 2 – Transmit diversity
This mode sends the same information through various antennas, each antenna has different coding and frequency resources. It is the MIMO mode (Multiple Input Multiple Output).

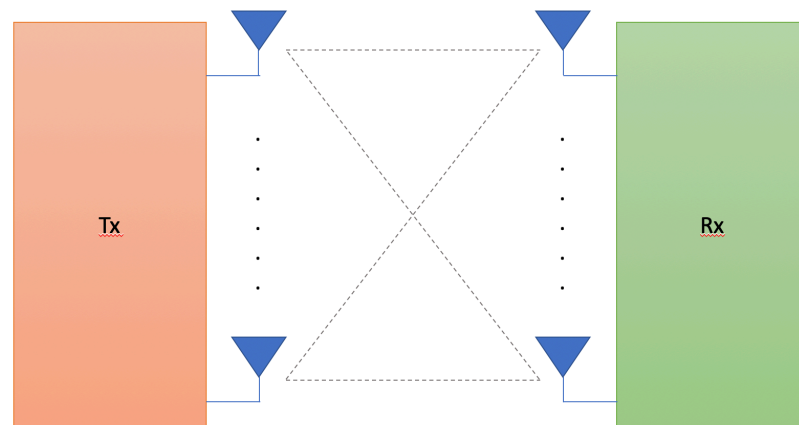


Figure 9. MIMO system characterisation

- TM 3 – Open loop spatial multiplexing with CDD
This mode supports spatial multiplexing, it requires less UE feedback regarding the channel situation and it is used when channel information is missing or the channel rapidly changes.

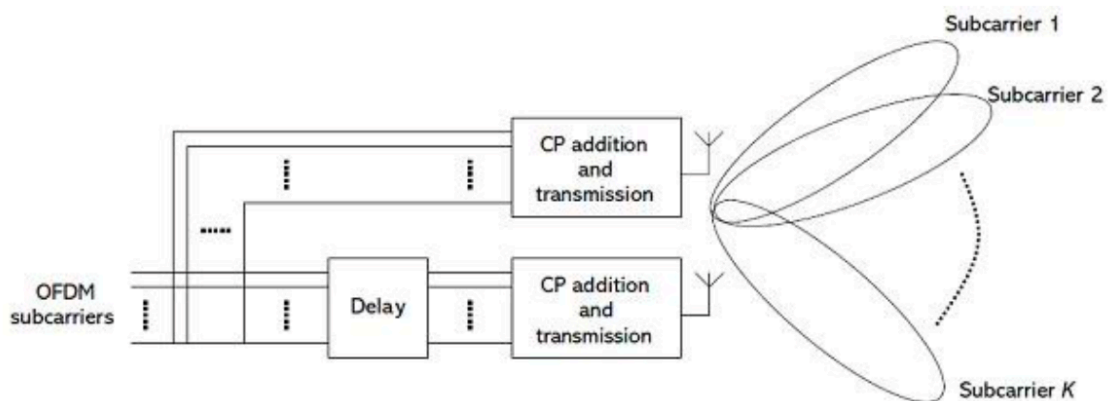


Figure 10. Spatial multiplexing with CDD

- TM 4 – Closed loop spatial multiplexing
To permit channel estimation at the receiver, the base station transmits cell-specific reference signals, distributed over various resource elements and over various timeslots. The UE sends a response regarding the channel situation, which includes information about which precoding is preferred from the defined codebook. This is accomplished using an index (precoding matrix indicators) defined in the codebook, a table with possible precoding matrices that is known to both sides.

3 Methodology

The methodology applied in this final degree thesis can be explained in four phases:

The documentation phase, where I get familiar with all the theory and nomenclature used in the 4th and 5th generation mobile networks, as well as the functioning and requirements of the demonstration platform to deploy the local network.

Then, the deployment phase, where I connect the hardware, install the software and learn how to start the mobile network. This phase includes to program test SIMs and subscribe them into the system, and configuring a commercial mobile phone.

The third phase is the performance analysis, where I deep into the network configuration and perform test with a commercial mobile phone in different scenarios and configurations.

And the last phase is the writing phase, where I write a user manual for future researchers and also this final document.

Hardware used in this project is:

- Two computers Lenovo ThinkCentre with:
Processor: Intel® Core™ i5-10600 CPU @ 3.30GHz x 12
Graphics: Mesa Intel® UHD Graphics 630 (CML GT2) / NV138
- One Universal Software Radio Peripheral (USRP) B210
- Four antennas
- Cell phone model Huawei P20 Lite
- SIM card reader
- Programmable SIM card sysmoUSIM-SJS1
- USB 3.0 wire

Software install on the computers and used to implement the network utilities is:

- srsRAN software
- USRP Hardware Driver (UHD) Repository
- srsGUI Repository
- PySim Repository

Downloaded applications on the phone

- Opensignal
- Network Cell Info

Before going any further, it is necessary to say that all the installation and configuration has been done on the Ubuntu 20.04.3 LTS system. To facilitate the installation of programs, drivers, libraries and others you can use the apt-get command.

As we are going to download some open-source projects it is necessary to download and install git. Git is a distributed version-control for tracking changes in source code during the development of a project, it is free, open-source and also allows an easy coordination among programmers.

```
$ sudo apt-get update  
$ sudo apt-get install git
```

4 Project development

In this chapter I detail the main contributions of the deployment phase, starting with the installation of all the drivers and libraries necessary for the use of the hardware and the demonstration platform.

The basic scheme of the assembly to be carried out is shown in Figure 11. As can be seen, both the EPC and the eNB will be running on their own computer. The USRP will be connected to the eNB computer through a USB 3.0 wire, and the 4 antennas will be connected to this USRP.

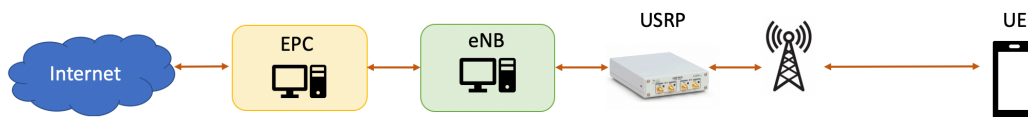


Figure 11. Assembly diagram

The USRP is a peripheral that is designed to implement Software Defined Radio (SDR) systems, it. It has 2 channels with continuous RF coverage from 70MHz to 6GHz, full duplex, MIMO (2 Tx and 2 Rx, as it can be seen on the Figure 12) [7].



Figure 12. USRP connectors

The LEDs next to each of the connections points have the indicator code described in the Table 2, they will blink off in a temporary transmit underflow or received overflow condition, indicating that the host is not sending or receiving samples fast enough. The host will be notified of the condition and output a “U” or “O” [7].

LED	Description	Color	Indication
TX /Rx	Indicates the state of transmission of the device.	Off	No activity
		Green	Receiving
		Red	Transmitting
		Orange	Switching between transmitting and receiving
RX2	Indicates the state of reception of the device.	Off	No activity
		Green	Receiving

Table 2. USRP B210 LED indicators and their meanings

The final assembly in the laboratory is shown in the Figure 13. On the left computer is the EPC, on the right computer with the graphics is the eNB. Connected to the eNB, in front of the black tower, is the USRP B210 and on the far right of the picture you can see the 4 antennas. The UE is the phone on top of the table containing the SIM card.

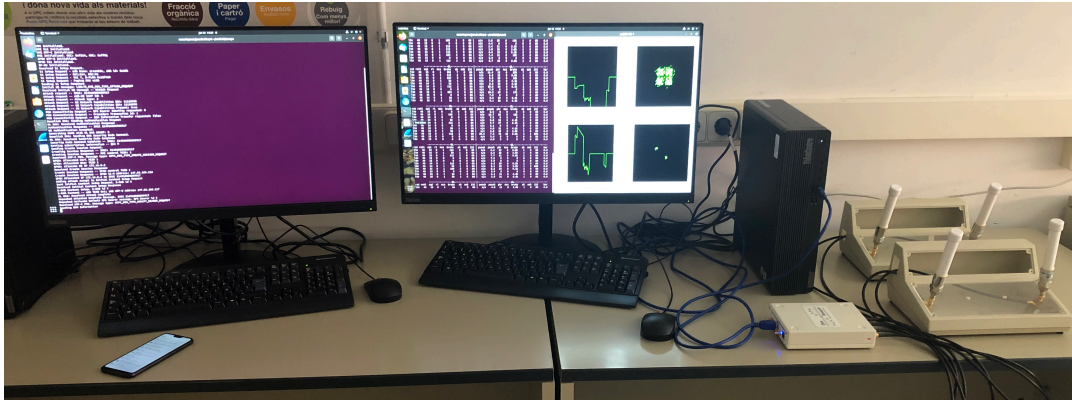


Figure 13. Photograph of the assembly in the laboratory

As mentioned before, the software that is going to be used is the srsRAN. This software is evolving towards 5G and at the moment only exists in NSA mode. That is why to create a Beyond 5G scenario with this software, we start by setting up a 4G LTE network where the gNodeB will be connected in the future.

In the next section, I will explain the installation of the programs needed to set up the LTE network, but first it is necessary to download the required libraries for each one of them. These libraries can be found at Appendix A: Libraries and commands

4.1 UHD Installation

The USRP Hardware Driver (UHD) is a library that communicates with and controls the USRP device, it is a free and open-source software driver and it is distributed by the Ettus Research company. For the UHD are required several libraries to be installed on the computer, depending on the USRP model those instructions will vary, in this project the model that has been used is the B210. Now for downloading the UHD repository and install it:

```

$ mkdir uhd
$ git clone https://github.com/EttusResearch/uhd
$ cd uhd
$ git checkout release_003_010_000_000
$ cd host
$ mkdir build
$ cd build
$ cmake ..
$ make
$ make test
$ sudo make install
$ sudo ldconfig
$ sudo uhd_images_downloader
    
```

Once the installation has been completed, it is necessary to check that the UHD detects the USRP with the command “uhd_find_devices” on Figure 14, and then with “uhd_usrp_probe” on Figure 15, the full capture is in Appendix A: Libraries and commands.

```

usuarlogrcm@srsdesktop2:~$ uhd_find_devices
[INFO] [UHD] linux; GNU C++ version 9.4.0; Boost_107100; UHD_4.3.0.0-15-g5333d3d1
-----
-- UHD Device 0
-----
Device Address:
  serial: 30D3F45
  name: MyB210
  product: B210
  type: b200
  
```

Figure 14. uhd_find_devices command capture

```

usuarlogrcm@srsdesktop2:~$ sudo uhd_usrp_probe
[INFO] [UHD] linux; GNU C++ version 9.3.0; Boost_107100; UHD_4.2.0.git-121-g748162e6
[INFO] [B200] Detected Device: B210
[INFO] [B200] Loading FPGA image: /usr/local/share/uhd/images/usrp_b210_fpga.bin...
[INFO] [B200] Operating over USB 2.
[INFO] [B200] Detecting internal GPSDO....
[INFO] [GPS] No GPSDO found
[INFO] [B200] Initialize CODEC control...
[INFO] [B200] Initialize Radio control...
[INFO] [B200] Performing register loopback test...
[INFO] [B200] Register loopback test passed
[INFO] [B200] Performing register loopback test...
[INFO] [B200] Register loopback test passed
[INFO] [B200] Setting master clock rate selection to 'automatic'.
[INFO] [B200] Asking for clock rate 16.000000 MHz...
[INFO] [B200] Actually got clock rate 16.000000 MHz.

-----
Device: B-Series Device
-----
  Mboard: B210
  serial: 30D3F45
  name: MyB210
  product: 2
  revision: 4
  FW Version: 8.0
  FPGA Version: 16.0

  Time sources: none, internal, external, gpsdo
  Clock sources: internal, external, gpsdo
  Sensors: ref_locked

-----
  RX DSP: 0
  Freq range: -8.000 to 8.000 MHz

-----
  RX DSP: 1
  Freq range: -8.000 to 8.000 MHz
  
```

Figure 15. uhd_usrp_probe command capture

4.2 srsGUI Installation

We also have downloaded the srsGUI software, which is a free and open-source graphics library for Software Defined Radio (SDR). This library provides plot for real and complex numbers, in this case it is going to be used for real-time plotting.

```

$ git clone https://github.com/srsLTE/srsGUI.git
$ cd srsgui
$ mkdir build
$ cd build
$ cmake ../
$ make
  
```

Finally, after ensuring that the above programs have been downloaded and installed correctly, srsRAN software can be installed, otherwise dependency issues with the libraries would arise.

4.3 srsRAN Installation

The srsRAN software is a free open-source 4G and 5G software radio suit. Featuring both UE and eNodeB/gNodeB applications, srsRAN can be used with third-party core network

solutions to build complete end-to-end mobile wireless networks [8]. It is a software developed in C++, its structure makes it very accessible to implement any modification you want to make in the code since the names of the classes and variables identify each of the elements that make up an LTE network. It includes:

- srsEPC is a lightweight implementation of a complete LTE core network. The srsEPC application runs as a single binary but provides the key EPC components of HSS, MME, S/P-GW.
- srsENB is a complete SDR LTE eNodeB application.
- srsUE is a 4G LTE and 5G NR UE modem implemented entirely in software. It connects to any LTE or 5G NR network and provides a standard network interface with high-speed mobile connectivity.

The following commands download and install this software:

```
$ mkdir srsRAN
$ git clone https://github.com/srsRAN/srsRAN.git
$ cd srsRAN
$ mkdir build
$ cd build
$ cmake ../
$ make
```

To finish the Installation of srsRAN and generate the configuration files in the folder `~/config/srsran`, the next commands have been used:

```
$ sudo make install
$ srsran_install_configs.sh user
```

Once the software is installed, changes will have to be made to the generated files with the necessary parameters to set up the network. In this configuration, the EPC and the eNB will be placed in two different computers, although it is possible to place them in the same one. In this project, a programmable SIM card in a mobile phone has been used as the UE and it has not been possible to have a second USRP to test the srsUE on a third computer.

As the UE it has been used a programmable SIM card in a mobile phone and the option to configure the srsUE has not been possible to carry out because a second USRP was not available.

4.4 SIM Configuration

The chosen programme for programming SIM/USIM cards is PySim-prog, which is a small command line utility written in Python [9]. Before starting to program the card, a number of necessary data must be collected, some of which are set by the manufacturer and some of which are random. The Mobile Country Code (MCC) and Mobile Network Code (MNC) values are initially configured in the `epc.conf` file, so for the UE to be able to connect to the network these parameters will have to be the same in both places.

As it has been decided to make the network as realistic as possible, the MCC has the value 214, which is the one that identifies Spain, the CC (Country Code) has the value 34 and to assign the MNC value, it has been necessary to consult which numbers were not being used by any operator and 91 has been assigned. The parameters necessary to be able to configure the SIM card that must be obtained from the manufacturer are the following:

- Administrator PIN
- IMSI number
- ICCID number
- Ki (key) number

```

Using PC/SC reader interface
Ready for Programming: Insert card now (or CTRL-C to cancel)
Generated card parameters :
> Name      : Magic
> SMSP     : e1ffffffffffffffffffffffff058100435555ffffffffffff000000
> ICCID    : 8934211000000099179
> MCC/MNC  : 214/91
> IMSI     : 214910000009917
> Ki       : C4AC6C875021BD7BA08C4FD6CB14072D
> OPC      : a136b666013250f4d7ed181cf64d8c50
> ACC      : None
> ADM1(hex): 3935363430383739
> OPMODE   : None
Programming ...
Programming successful: Remove card from reader
    
```

Figure 16. Parameters programmed into the SIM

4.5 srsRAN Configuration

4.5.1 EPC

Now all that remains is to configure the srsRAN files, for this it is necessary to know the IP addresses of each of the computers and the parameters configured on the SIM card. First the modification will be made to the EPC file, the fields that have to be modified are:

- MCC and MNC with the same values as in the Sim card.
- mme_bind_addr and gtpu_bind_addr with the IP address of the computer where the EPC is going to be located.

The changes described are found in the [mme] and [spgw] sections of the epc.conf file located in the .conf folder.

```

[mme]
mme_code = 0x1a
mme_group = 0x0001
tac = 0x0007
mcc = 214
mnc = 91
mme_bind_addr = 147.83.105.216
apn = srsapn
dns_addr = 8.8.8.8
encryption_algo = EEA0
integrity_algo = EIA1
paging_timer = 2
request_imeisv = false

#####

[spgw]
gtpu_bind_addr = 147.83.105.216
sgi_if_addr = 172.16.0.1
sgi_if_name = srs_spgw_sgi
max_paging_queue = 100
    
```

4.5.2 HSS

The UE has to be entered in the database that the EPC is going to read to allow the connection. The name, IMSI, Key and OPC have to be the same values that have been programmed into the card. The algorithm that the sysmoUSIM-SJS1 uses is the MILENAGE, set by the manufacturer, and the IP allocation will be dynamic.

```
magic,mil,214910000009917,c4ac6c875021bd7ba08c4fd6cb14072d,opc,a136b666013250f4d7ed181cf64d8c50,9000,00000000107,9,dynamic
```

4.5.3 eNB

In the enb.conf file it is possible to configure more advanced options such as channel emulators, packet capturing, scheduler options, etc. which have not been used in this project. The modifications that have been made are:

- MCC and MNC same as in the epc.conf and the Sim card.
- mme_addr with the IP address of the actual computer where the EPC is going to be located.
- gtp_bind_addr and s1c_bind_addr with the IP address of the actual computer where the eNB is going to be located.
- To obtain the real-plot of the channel by the srsGUI, set the variable to true.

The changes described are found in the [enb] and [gui] sections of the enb.conf file located in the .conf/srsran folder.

```
[enb]
enb_id = 0x19B
mcc = 214
mnc = 91
mme_addr = 147.83.105.216
gtp_bind_addr = 147.83.105.217
s1c_bind_addr = 147.83.105.217
s1c_bind_port = 0
n_prb = 50
#tm = 4
#nof_ports = 2

#####
[gui]
enable = false
```

The number of carriers (in code n_prb) and the transmission mode (in code tm) can be changed. The values that n_prb can take are the same as those in the PRB row of the Table 1, each one configures a different channelling with a different speed. The different transmission modes are listed in the Table 3, with the exception of mode 1, for all other modes it must be specified the number of input ports.

Mode 1	Single antenna
Mode 2	Transmit diversity
Mode 3	CDD (Cyclic Delay Diversity)
Mode 4	Closed-loop spatial multiplexing

Table 3. Possible transmission modes in srsRAN

4.5.4 UE

At this point, the SIM card must be inserted, it must be configured an Access Personal Point on the phone and a mobile network search must be performed. The network initially appears as MCC+MNC and when the information is received from the MME it is renamed "SoftwareRadio Systems RAN 4G".

4.6 Common implementation errors

4.6.1 Dependencies

At the beginning of the installation there were several bugs related to the front-end device that were caused by library dependencies. It is important to follow the installation order leaving the srsRAN software to the end, otherwise you will have to remove everything and start again with the installation.

4.6.2 IP addresses

Several problems with the IP addresses of the computer used, the EPC part and the eNB part were faced in this implementation, but these can be avoided following the tips of the installation in the srsRAN documentation. If the IP addresses identifying each computer are not set correctly in the configuration files, it will cause the eNB to not connect on the "srs_spgw_sgi" virtual network interface created by the EPC run.

4.6.3 Frequency band allocation

It is necessary to check that the frequency band configured in the eNB matches the frequency band configured in the mobile phone. You can find out which bands your phone model works in by searching the internet or sometimes by accessing the factory settings, if available. In case they do not work on the same frequencies, it will not be possible for the configured network to be displayed in the mobile network search of the mobile phone. The solution would be to change the value of dl_earfcn in the enb.conf file to one that the phone could detect.

4.6.4 Random errors

If the USRP B210 has been in operation for a period of time, it may start giving random errors every time you try to run the program. The solution to this is to turn off the computer, as it does not have a separate power supply, allow a few minutes to pass and then turn the computer back on.

4.6.5 Overflow

There is an overflow problem at the UHD level that could be due to USB drivers, UHD drivers, CPU speed, power mode of the host... To minimize this problem the solution given by the developers is to disable the frequency scaling on the CPU where the eNB is located and to make sure that the USRP is connected to a USB 3.0 port.

4.7 Establishing connection

It is necessary to open a command window on each computer where each part of the network is going to be executed. On the first computer we execute the command 'sudo srsepc epc.conf' and on the second computer we execute 'sudo srsenb enb.conf'. The display should show logs similar to those shown in Figure 17.

```

usuariogrcm@srsdesktop1:~/srsRAN/srsepc$ sudo srsepc epc.conf
Built in Release mode using commit 5275f3336 on branch master.

--- Software Radio Systems EPC ---

Reading configuration file epc.conf...
HSS Initialized.
MME S11 Initialized.
MME GTP-C Initialized.
MME Initialized, MCC: 0xf214, MNC: 0xf91
SPGW GTP-U Initialized.
SPGW S11 Initialized.
SP-GW Initialized.
Received S1 Setup Request.
S1 Setup Request - eNB Name: srsenb01, eNB id: 0x19b
S1 Setup Request - MCC:214, MNC:91
S1 Setup Request - TAC 7, B-PLMN 0x12f419
S1 Setup Request - Paging DRX v128
Sending S1 Setup Response
    
```

Figure 17. EPC logs without UE connected

As can be seen in the last lines, the eNB has already connected to the interface created by the EPC, at this moment the different gateways that communicate the access network with the core network have been created and are ready to exchange information and both are now waiting for a UE to connect. The Figure 18 shows the values of the measurements taken from the connection between the network and the UE. For a better understanding, Table 4 shows the meaning of each metric obtained in the downlink (DL) and uplink (UL). Throughout the connection, the tables shown on Figure 18 will be repeated on the terminal where the eNB is running, displaying the new values obtained.

```

usuariogrcm@srsdesktop2:~/srsRAN/srsenb$ sudo srsenb enb.conf
--- Software Radio Systems LTE eNodeB ---

Reading configuration file enb.conf...
Couldn't open sib.conf, trying /root/.config/srsran/sib.conf
Couldn't open rr.conf, trying /root/.config/srsran/rr.conf
Couldn't open rb.conf, trying /root/.config/srsran/rb.conf

Built in Release mode using commit 5275f3336 on branch master.

Opening 1 channels in RF device=UHD with args=default
Available RF device list: UHD zmq
[INFO] [UHD] linux; GNU C++ version 9.4.0; Boost_107100; UHD_4.3.0.0-15-g5333d3d1
[INFO] [LOGGING] Fastpath logging disabled at runtime.
Opening USRP channels=1, args: type=b200, master_clock_rate=23.04e6
[INFO] [UHD RF] RF UHD Generic instance constructed
[INFO] [B200] Detected Device: B210
[INFO] [B200] Operating over USB 2.
[INFO] [B200] Initialize CODEC control...
[INFO] [B200] Initialize Radio control...
[INFO] [B200] Performing register loopback test...
[INFO] [B200] Register loopback test passed
[INFO] [B200] Performing register loopback test...
[INFO] [B200] Register loopback test passed
[INFO] [B200] Asking for clock rate 23.040000 MHz...
[INFO] [B200] Actually got clock rate 23.040000 MHz.

==== eNodeB started ====
Type <t> to view trace
Setting frequency: DL=2680.0 Mhz, UL=2560.0 MHz for cc_idx=0 nof_prb=15
t
Enter t to stop trace.
RACH: tti=2691, cc=0, preamble=42, offset=1, temp_crnti=0x46

-----DL-----|-----UL-----
rat rnti  cqi  ri  mcs  brate  ok  nok  (%)  |  pusch  pucch  phr  mcs  brate  ok  nok  (%)  |  bsr
lte 46  15  0  4  598  3  0  0%  |  24.3  4.9  33  7  7.1k  5  0  0%  |  0.0
lte 46  15  0  0  56  1  0  0%  |  24.0  2.8  28  18  4.4k  1  0  0%  |  0.0
lte 46  15  0  0  0  0  0  0%  |  n/a  1.8  0  0  0  0  0  0%  |  0.0
lte 46  15  0  0  0  0  0  0%  |  n/a  2.1  0  0  0  0  0  0%  |  0.0
lte 46  15  0  0  0  0  0  0%  |  n/a  3.3  0  0  0  0  0  0%  |  0.0
lte 46  15  0  0  0  0  0  0%  |  n/a  1.9  0  0  0  0  0  0%  |  0.0
lte 46  15  0  0  0  0  0  0%  |  n/a  1.6  0  0  0  0  0  0%  |  0.0
lte 46  15  0  0  0  0  0  0%  |  n/a  2.1  0  0  0  0  0  0%  |  0.0
lte 46  15  0  0  0  0  0  0%  |  n/a  3.2  0  0  0  0  0  0%  |  0.0
lte 46  15  0  0  0  0  0  0%  |  n/a  2.6  0  0  0  0  0  0%  |  0.0
lte 46  15  0  0  0  0  0  0%  |  n/a  3.8  0  0  0  0  0  0%  |  0.0
    
```

Figure 18. eNB logs with UE connected

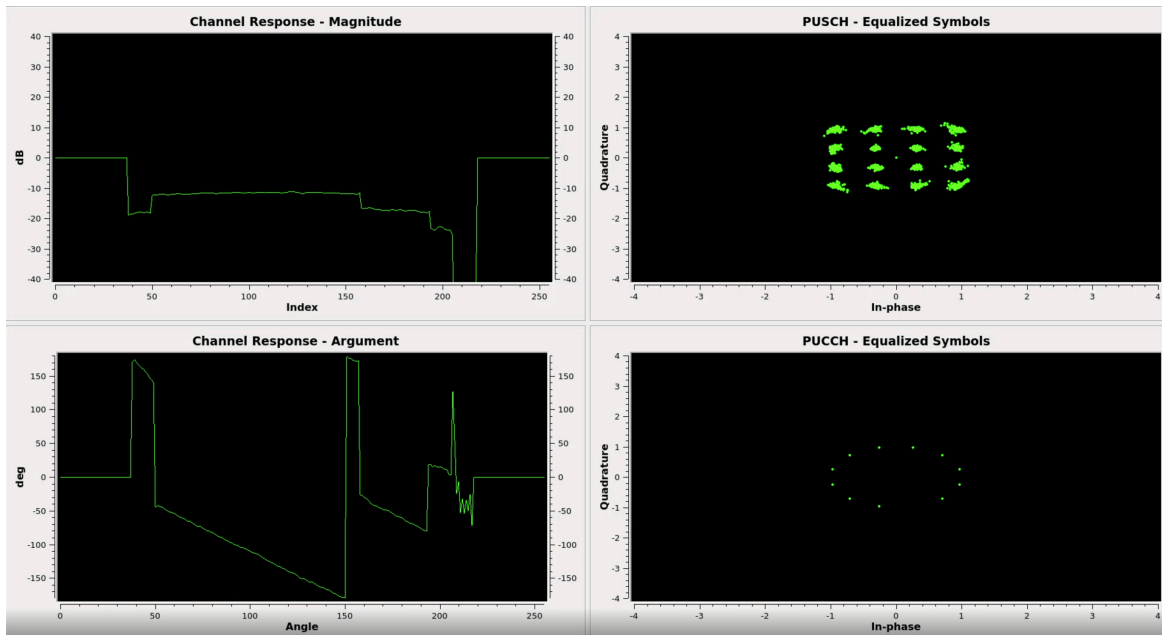


Figure 19. Capture of the srsGUI interface

Abbreviation	Meaning
rat	The RAT being used, either NR or LTE
pci	Physical Cell Identifier
rnti	Radio Network Temporary Identifier (UE identifier)
cqi	Channel Quality Indicator reported by the UE (1-15)
ri	Rank Indicator reported by the UE (dB)
mcs	Modulation and coding scheme (0-28)
brate	Bit rate (bits/sec)
ok	Number of packets successfully sent
nok	Number of packets dropped
(%)	Percentage of packets dropped
pusch	PUSCH SNIR (Signal-to-Interference-plus-Noise Ratio)
pucch	PUCCH SNIR
phr	Power Headroom (dB)
bsr	Buffer Status Report – data waiting to be transmitted as reported by the UE (bytes)

Table 4. Metrics provided on a per-UE for the DL and the UL respectively

5 Results

This section describes the tests that have been carried out and the values obtained from the network connection created with a mobile phone. Two free applications called Opensignal and Network Cell Info Lite have been downloaded to the mobile phone used to carry out the speed tests. In view of the differences between the results obtained from the tests, it follows that the values are measured at different levels. Before continuing, the eNB logs have been edited leaving the tables with the highest values due to the amount of data generated while testing from the mobile phone. The full logs can be found at Appendix C: Complete Measurement Logs

The two modes that make sense to test in a laboratory environment and taking into account the performance of the USRP are single antenna and transmit diversity. USRP performance limits the distance the UE can be moved to a few metres without seriously compromising the connection, which is why the Cyclic Delay Diversity mode, that is the specified mode for long distances, has no place in the tests run in the lab. The network could only be detected with a single mobile phone, which is why the Closed-Loop Spatial Multiplexing mode was also excluded from the tests.

There have been several problems with the mobile phone connecting to the different network configurations. The only solution available was to replace the smartphone for the other phones in the laboratory, but none of them was able to detect the network and it was necessary to return to the phone that had been used initially.

With the initial model and all parts of the network connected it was time to check the results of the tests that could be carried out, but there were some drawbacks that limited the number of possible tests.

Initially, different configurations were planned to test the performance of each configuration, but there were only a few where the phone actually could connect and maintain a stable connection to the network. In some of them with the single antenna mode, when the PRB value was greater than 6 an overflow message was displayed due to a desynchronization between the computer's CPU and the USRP B210. Once the two devices could be synchronised, a partial solution was achieved where the problem now occurred but for PRB greater than 15. A short connection was achieved with 25 PRB but it was not stable enough to run the tests. In the case of the Transmit Diversity mode the mobile phone was not able to detect the network at all, which resulted in the fact that no tests could be carried out with this configuration.

5.1 Test 1 - Single antenna and PRB with value 6

The test consists of setting the number of PRBs to 6, thereby setting the channel bandwidth to 1.4MHz, switching on the network and connecting the UE. Once the connection has been established, it is time to perform speed tests with the Opensignal and the Network Cell Info applications. By setting the PRBs value to 6 the level of the raw peak user speed is 5.1 Mbps (Table 1).

As you can see in both images there are some discrepancies between the values obtained by the tests carried out by the mobile applications and the values obtained by the eNB. There is a large difference between the two downlink tests performed, with the Opensignal test obtaining a value far above the maximum value shown in eNB.

The mobile phone test done with Network Cell Info receives a download speed of 3.2Mbps and the Opensignal has 4.72 Mbps, the maximum value we find in the tables given by the eNB (in the Figure 22) is 3.5Mbps. Nothing like what happens in the uplink where the three values are quite similar, the Network Cell Info Lite has 1.6Mbps, the Opensignal has 1.52Mbps and the eNB shows 1.8Mbps as maximum value.

In the case of both downlink and uplink the percentage of dropped packets is 0 and with similar values for the number of successfully sent packets. At peak uplink transmission time, as reported by the UE, the amount of data waiting to be transmitted rises to a maximum of 111KB.

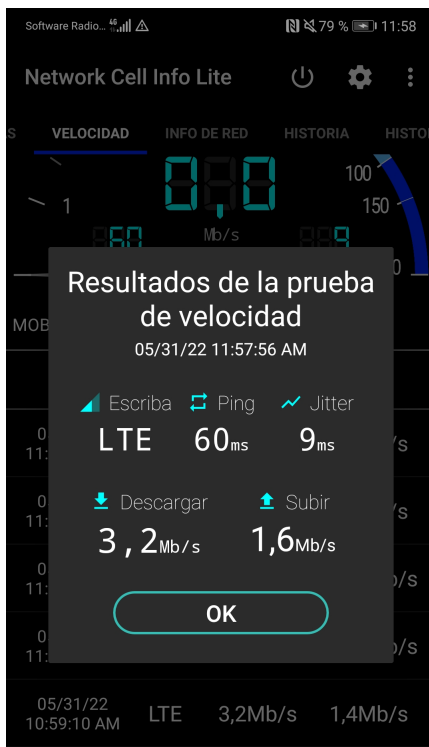


Figure 20. Speed test on cell phone with PRB=6 with Network Cell Info Lite

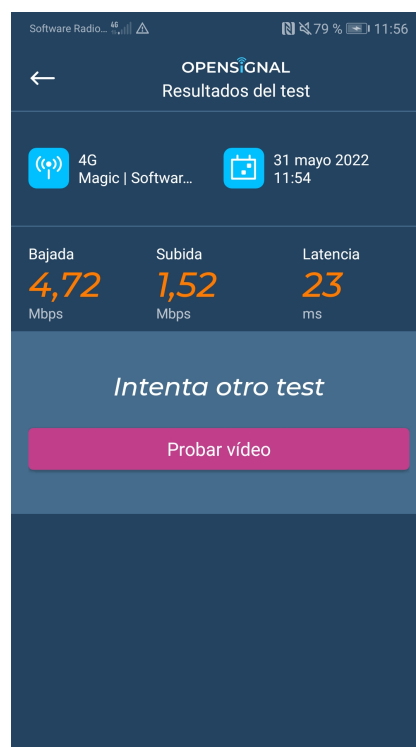


Figure 21. Speed test on cell phone with PRB=6 with Opensignal

--- Software Radio Systems LTE eNodeB ---

```
Reading configuration file enb.conf...
Opening 1 channels in RF device=UHD with args=default
Available RF device list: UHD zmq
[INFO] [UHD] linux; GNU C++ version 9.4.0; Boost_107100; UHD_4.3.0.0-15-g5333d3d1
[INFO] [LOGGING] Fastpath logging disabled at runtime.
Opening USRP channels=1, args: type=b200, master_clock_rate=23.04e6
[INFO] [UHD RF] RF UHD Generic instance constructed
[INFO] [B200] Detected Device: B210
[INFO] [B200] Operating over USB 3.
[INFO] [B200] Initialize CODEC control...
[INFO] [B200] Initialize Radio control...
[INFO] [B200] Performing register loopback test...
[INFO] [B200] Register loopback test passed
[INFO] [B200] Performing register loopback test...
[INFO] [B200] Register loopback test passed
[INFO] [B200] Asking for clock rate 23.040000 MHz...
[INFO] [B200] Actually got clock rate 23.040000 MHz.
```

```
==== eNodeB started ====
Type <t> to view trace
Setting frequency: DL=2680.0 Mhz, UL=2560.0 MHz for cc_idx=0 nof_prb=6
RACH: tti=9801, cc=0, preamble=25, offset=1, temp_crnti=0x46
t
Enter t to stop trace.
```

[...]

DL								UL									
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	26	3.5M	899	0	0%	22.5	23.1	39	20	108k	66	0	0%	0.0
lte	47	15	0	26	3.5M	901	0	0%	22.6	25.0	39	19	130k	94	0	0%	0.0
lte	47	15	0	26	3.5M	900	0	0%	22.6	25.1	39	19	128k	97	0	0%	0.0
lte	47	15	0	26	3.5M	900	0	0%	22.9	24.9	39	19	140k	107	0	0%	0.0
lte	47	15	0	26	3.5M	900	0	0%	22.6	24.3	39	19	167k	124	0	0%	0.0
lte	47	15	0	26	3.5M	900	0	0%	22.5	23.5	38	21	103k	58	0	0%	0.0
lte	47	15	0	26	3.5M	899	0	0%	22.9	22.4	38	20	207k	139	0	0%	0.0
lte	47	15	0	26	2.7M	710	0	0%	22.7	21.0	38	21	209k	120	0	0%	6.00k
lte	47	15	0	19	56k	129	0	0%	22.2	n/a	38	23	1.8M	900	0	0%	10.3k
lte	47	15	0	19	43k	91	0	0%	21.9	n/a	39	23	1.8M	901	0	0%	22.9k
lte	47	15	0	17	42k	100	0	0%	21.9	n/a	39	23	1.8M	900	0	0%	38.4k

[...]

DL								UL									
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	18	51k	102	0	0%	21.7	n/a	39	23	1.8M	899	0	0%	48.5k
lte	47	15	0	18	43k	100	0	0%	21.8	n/a	39	23	1.8M	900	0	0%	70.6k
lte	47	15	0	19	42k	88	0	0%	21.6	n/a	39	23	1.8M	900	0	0%	108k
lte	47	15	0	18	72k	125	0	0%	22.1	n/a	38	23	1.8M	900	0	0%	109k
lte	47	15	0	18	92k	139	0	0%	21.8	n/a	38	23	1.8M	901	0	0%	111k
lte	47	15	0	20	66k	134	0	0%	21.8	n/a	39	23	1.8M	900	0	0%	94.3k
lte	47	15	0	18	58k	111	0	0%	21.8	n/a	39	23	1.8M	899	0	0%	96.3k
lte	47	15	0	18	42k	100	0	0%	21.9	n/a	38	23	1.8M	900	0	0%	95.6k
lte	47	15	0	19	43k	96	0	0%	22.3	n/a	38	23	1.8M	900	0	0%	92.5k
lte	47	15	0	17	43k	100	0	0%	22.1	n/a	38	23	1.8M	900	0	0%	95.3k
lte	47	15	0	17	42k	98	0	0%	22.5	n/a	38	23	1.8M	900	0	0%	5.74k

[...]

DL								UL									
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	0	0	0	0	0%	n/a	1.9	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	3.2	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	4.7	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	3.5	0	0	0	0	0	0%	0.0
lte	47	15	0	0	112	2	0	0%	21.0	2.8	40	23	4.0k	2	0	0%	0.0
lte	47	15	0	10	1.4k	4	0	0%	21.2	5.4	40	23	4.0k	2	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	2.7	0	0	0	0	0	0%	0.0

```
Stopping ..
--- exiting ---
```

Figure 22. eNB logs with PRB=6

5.2 Test 2 - Single antenna and PRB with value 15

The test consists of setting the number of PRBs to 15, thereby setting the channel bandwidth to 3MHz, switching on the network and connecting the UE. Once the connection has been established, perform speed tests with the Opensignal and the Network Cell Info applications. By setting the PRBs value to 15 the level of the raw peak user speed is 12.8 Mbps (Table 1).

We see discrepancies between the values obtained by the tests carried out by the mobile applications and the values obtained by the eNB. There is a large difference between the two downlink tests performed, with the Opensignal test being the closest above the maximum value obtained in the eNB.

Whereas the mobile phone test done with Network Cell Info Lite receives a download speed of 9.8Mbps and the Opensignal of 11.5Mbps, the maximum value we find in the tables given by the logs of the eNB (Figure 25) is 11Mbps. The difference between the mobile tests is maintained in the upload speed study but on a smaller scale. In this case the Opensignal and the eNB match with the value of 5.6Mbps.

During the testing process both downlink and uplink the percentage of dropped packets is nearly 0 and with similar values for the number of successfully sent packets. At peak uplink transmission time, as reported by the UE, the amount of data waiting to be transmitted rises to a maximum of 150KB.

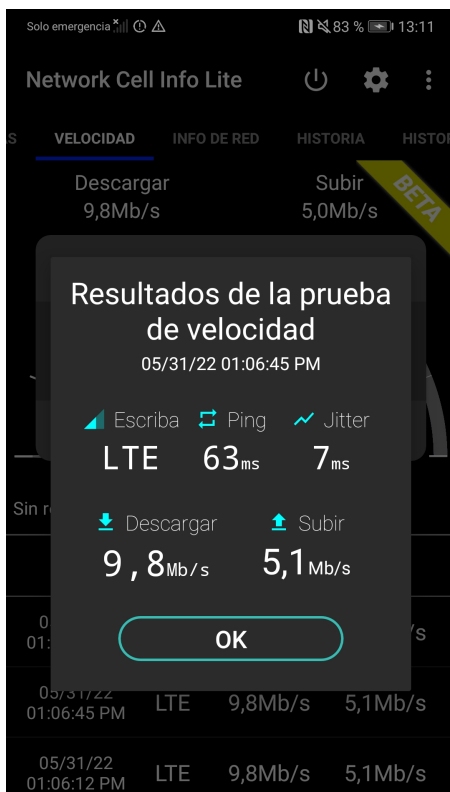


Figure 23. Speed test on cell phone with PRB=15 with Network Cell Info Lite

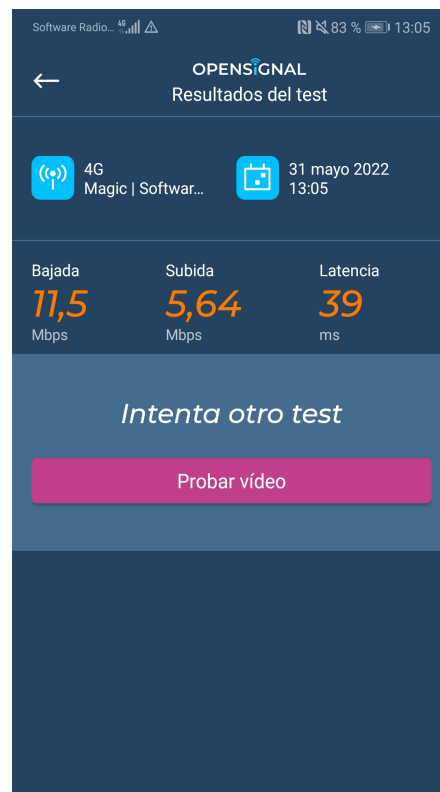


Figure 24. Speed test on cell phone with PRB=6 with Opensignal

--- Software Radio Systems LTE eNodeB ---

```

Reading configuration file enb.conf...
Opening 1 channels in RF device=UHD with args=default
Available RF device list: UHD zmq
[INFO] [UHD] linux; GNU C++ version 9.4.0; Boost_107100; UHD_4.3.0.0-15-g5333d3d1
[INFO] [LOGGING] Fastpath logging disabled at runtime.
Opening USRP channels=1, args: type=b200,master_clock_rate=23.04e6
[INFO] [UHD RF] RF UHD Generic instance constructed
[INFO] [B200] Detected Device: B210
[INFO] [B200] Operating over USB 3.
[INFO] [B200] Initialize CODEC control...
[INFO] [B200] Initialize Radio control...
[INFO] [B200] Performing register loopback test...
[INFO] [B200] Register loopback test passed
[INFO] [B200] Performing register loopback test...
[INFO] [B200] Register loopback test passed
[INFO] [B200] Asking for clock rate 23.040000 MHz...
[INFO] [B200] Actually got clock rate 23.040000 MHz.
  
```

==== eNodeB started ===

Type <t> to view trace

Setting frequency: DL=2680.0 Mhz, UL=2560.0 MHz for cc_idx=0 nof_prb=15

RACH: tti=991, cc=0, preamble=11, offset=1, temp_crnti=0x46

[...]

DL									UL								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	27	11M 1001	0	0%	0%	27.3	29.2	29	21	301k	97	0	0%	0.0
lte	47	15	0	27	11M 1000	0	0%	0%	27.3	29.4	29	21	324k	91	0	0%	0.0
lte	47	15	0	27	11M 999	0	0%	0%	26.6	29.4	30	22	910k	184	0	0%	0.0
lte	47	14	0	27	11M 1001	0	0%	0%	24.7	28.6	28	21	4.4M	841	0	0%	3.54k
lte	47	14	0	27	11M 1000	0	0%	0%	27.3	29.0	28	22	5.4M	959	0	0%	47.3k
lte	47	15	0	27	11M 999	0	0%	0%	24.7	n/a	30	23	5.6M	999	0	0%	126k
lte	47	15	0	27	11M 1001	0	0%	0%	23.3	n/a	28	23	5.6M	1001	0	0%	145k
lte	47	15	0	26	8.8M 865	0	0%	0%	24.1	n/a	28	23	5.6M	999	0	0%	145k
lte	47	15	0	27	11M 1001	0	0%	0%	24.1	n/a	28	23	5.6M	1001	0	0%	148k
lte	47	15	0	27	11M 1000	0	0%	0%	24.3	n/a	28	23	5.6M	1000	0	0%	145k
lte	47	15	0	27	11M 999	0	0%	0%	24.4	n/a	30	23	5.6M	999	0	0%	148k

DL									UL								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	27	11M 1001	0	0%	0%	24.1	n/a	30	23	5.6M	1001	0	0%	149k
lte	47	15	0	27	10M 989	0	0%	0%	23.3	n/a	30	23	5.6M	1000	0	0%	147k
lte	47	15	0	27	9.7M 954	0	0%	0%	23.7	n/a	31	23	5.6M	999	0	0%	148k
lte	47	15	0	27	11M 1001	0	0%	0%	20.9	n/a	31	23	5.6M	1001	0	0%	146k
lte	47	15	0	27	11M 1000	0	0%	0%	20.2	n/a	31	22	5.6M	999	1	0%	149k
lte	47	15	0	27	11M 999	0	0%	0%	24.6	30.0	31	22	4.2M	768	0	0%	0.0
lte	47	15	0	27	11M 1001	0	0%	0%	26.8	29.3	30	21	393k	103	0	0%	0.0
lte	47	15	0	27	8.6M 814	0	0%	0%	27.4	29.6	32	20	373k	119	0	0%	0.0
lte	47	15	0	27	11M 988	0	0%	0%	27.5	30.0	29	22	775k	169	0	0%	0.0
lte	47	15	0	27	11M 1001	0	0%	0%	27.6	30.0	30	22	996k	207	0	0%	0.0
lte	47	15	0	27	11M 1000	0	0%	0%	27.6	30.0	30	21	954k	201	0	0%	255

DL									UL								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	27	11M 1000	0	0%	0%	27.5	30.0	30	22	1.1M	215	0	0%	0.0
lte	47	15	0	27	11M 1000	0	0%	0%	27.7	30.1	30	22	975k	218	0	0%	0.0
lte	47	15	0	27	11M 999	0	0%	0%	27.6	30.0	30	22	961k	206	0	0%	0.0
lte	47	15	0	27	11M 1001	0	0%	0%	27.5	29.9	30	22	980k	200	0	0%	252
lte	47	15	0	27	11M 1000	0	0%	0%	27.3	29.8	30	22	1.0M	211	0	0%	0.0
lte	47	15	0	27	11M 999	0	0%	0%	27.4	30.2	30	22	1.1M	215	0	0%	0.0
lte	47	15	0	27	11M 1001	0	0%	0%	27.4	30.1	30	22	964k	199	0	0%	252
lte	47	15	0	24	3.6M 413	0	0%	0%	27.1	28.0	30	22	1.5M	291	0	0%	150k
lte	47	15	0	12	124k 264	0	0%	0%	27.4	n/a	28	23	5.6M	999	0	0%	145k
lte	47	15	0	12	124k 263	0	0%	0%	28.5	n/a	28	23	5.6M	1001	0	0%	147k
lte	47	14	0	12	137k 286	0	0%	0%	25.6	n/a	28	23	5.6M	1000	0	0%	149k

[...]

Stopping ..

--- exiting ---

Figure 25. eNB logs with PRB=15

6 Budget

This budget gives us an idea of the cost of the project. To carry it out, it has been necessary to buy some components although others were already in the Mobile Communications Laboratory. In any case, the budget has been made by counting all the components used, the staff needed and as all the software used is open source, it has not been necessary to acquire any license.

In Table 5 it can be seen the breakdown of the components used and the units required, and in Table 6 the staff involved.

Concept	Price per unit	Quantity	Total Price	Amortization Period (years)	Annual Amortization	Monthly Amortization	Total
Pc + Screen	700€	2	1400€	8	175€	14.58€	72.90€
USRP B210	1952€	1	1952€	6	325.33	27.11€	135.55€
Antennas	53.11€	4	212.44€	6	35.41€	2.95€	14.75€
Huawei P20 Lite	200€	1	200€	6	33.33€	2.78€	13.90€
SysmoUSIM-SJS1 (10 cards)	80€	1	80€	-	-	-	80€
Total							317.10€

Table 5. Cost of the components used

Salary	Salary per hour (€/hour)	Hours/Week	Weeks	Total
Junior Engineer	10	25	22	5500€

Table 6. Project staff cost

With all that has been taken into account in the previous tables, the final budget can be found in the Table 7.

Concept	Total
Staff Salaries	5500€
Material	317.10€
Total	5817.10€

Table 7. Project Budget

7 Conclusions and future development

In this thesis, a local LTE network has been created with the intention that, in the future, with the evolution of the software used, a Beyond 5G scenario can be created. It is open source software which allows new algorithms and mechanisms to be tested on the platform.

The software used is srsRAN, which is open source and allows the network to be implemented in different ways. That is, the software is prepared to run the EPC, the eNB on one or two computers and run the UE on a separate computer or use a mobile phone. Due to the material available in the laboratory, it was only possible to study the mobile phone option, and as for where to run the EPC and the eNB, it was decided to run them on different computers due to the high consumption of resources involved in running each one.

From the results obtained, the use of a mobile phone limits the usable performance of the network set up to only a few configurations that are stable enough for speed tests. It is difficult to know where the problem lies for connections that cannot be established because of the limited information provided by the smartphone and the information obtained by the eNB is not sufficient.

With all of this, a future line of research would be to run the srsUE configuration offered by srsRAN on a computer with its own USRP, thereby obtaining information from both the eNB and the UE.

Another line of research is the use of an external reference clock for synchronisation of the different devices. The low accuracy of the carrier frequency at the RF front-end can also lead to the UE not being able to connect successfully or not seeing the network as the accuracy of the SDR front-ends is quite low.

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Appendix A: Libraries and commands

Required libraries for the UHD

```

sudo apt-get install autoconf automake build-essential ccache cmake cpufrequtils
doxygen ethtool \
g++ inetutils-tools libboost-all-dev libncurses5 libncurses5-dev libusb-1.0-0
libusb-1.0-0-dev \
libusb-dev python3-dev python3-mako python3-numpy python3-requests python3-scipy
python3-setuptools \
python3-ruamel.yaml
    
```

Full capture of the uhd_usrp_probe command:

```

vsuarlogrcm@srsdesktop2:~$ sudo uhd_usrp_probe
[INFO] [UHD] linux; GNU C++ version 9.3.0; Boost_107100; UHD_4.2.0.git-121-g748162e6
[INFO] [B200] Detected Device: B210
[INFO] [B200] Loading FPGA image: /usr/local/share/uhd/images/usrp_b210_fpga.bin...
[INFO] [B200] Operating over USB 2.
[INFO] [B200] Detecting internal GPSDO...
[INFO] [GPS] No GPSDO found
[INFO] [B200] Initialize CODEC control...
[INFO] [B200] Initialize Radio control...
[INFO] [B200] Performing register loopback test...
[INFO] [B200] Register loopback test passed
[INFO] [B200] Performing register loopback test...
[INFO] [B200] Register loopback test passed
[INFO] [B200] Setting master clock rate selection to 'automatic'.
[INFO] [B200] Asking for clock rate 16.000000 MHz...
[INFO] [B200] Actually got clock rate 16.000000 MHz.

-----
Device: B-Series Device
-----
Mboard: B210
serial: 30D3F45
name: MyB210
product: 2
revision: 4
FW Version: 8.0
FPGA Version: 16.0

Time sources: none, internal, external, gpsdo
Clock sources: internal, external, gpsdo
Sensors: ref_locked

-----
RX DSP: 0
Freq range: -8.000 to 8.000 MHz

-----
RX DSP: 1
Freq range: -8.000 to 8.000 MHz
    
```

Figure 26. Capture 1 of the command `uhd_usrp_probe`

```

RX Dboard: A
-----
RX Frontend: A
Name: FE-RX2
Antennas: TX/RX, RX2
Sensors: temp, rssi, lo_locked
Freq range: 50.000 to 6000.000 MHz
Gain range PGA: 0.0 to 76.0 step 1.0 dB
Bandwidth range: 200000.0 to 56000000.0 step 0.0 Hz
Connection Type: IQ
Uses LO offset: No

-----
RX Frontend: B
Name: FE-RX1
Antennas: TX/RX, RX2
Sensors: temp, rssi, lo_locked
Freq range: 50.000 to 6000.000 MHz
Gain range PGA: 0.0 to 76.0 step 1.0 dB
Bandwidth range: 200000.0 to 56000000.0 step 0.0 Hz
Connection Type: IQ
Uses LO offset: No
    
```

Figure 27. Capture 2 of the command `uhd_usrp_probe`

```

RX Codec: A
Name: B210 RX dual ADC
Gain Elements: None

TX DSP: 0
Freq range: -8.000 to 8.000 MHz

TX DSP: 1
Freq range: -8.000 to 8.000 MHz

TX Dboard: A

TX Frontend: A
Name: FE-TX2
Antennas: TX/RX
Sensors: temp, lo_locked
Freq range: 50.000 to 6000.000 MHz
Gain range PGA: 0.0 to 89.8 step 0.2 dB
Bandwidth range: 200000.0 to 56000000.0 step 0.0 Hz
Connection Type: IQ
Uses LO offset: No

TX Frontend: B
Name: FE-TX1
Antennas: TX/RX
Sensors: temp, lo_locked
Freq range: 50.000 to 6000.000 MHz
Gain range PGA: 0.0 to 89.8 step 0.2 dB
Bandwidth range: 200000.0 to 56000000.0 step 0.0 Hz
Connection Type: IQ
Uses LO offset: No

TX Codec: A
Name: B210 TX dual DAC
Gain Elements: None

usuari@grcm@srsdesktop2:~$
    
```

Figure 28. Capture 3 of the command `uhd_usrp_probe`

Required libraries for the srsGUI:

```
sudo apt-get install libboost-system-dev libboost-test-dev libboost-thread-dev
libqwt-gt5-dev qtbase5-dev
```

Required libraries for srsRAN:

```
sudo apt-get install build-essential cmake libfftw3-dev libmbdttls-dev libboost-
program-options-dev libconfig++-dev libsctp-dev
```

Required libraries for PySim:

```
sudo apt-get install pscd psc-tools libccid libpssc-lite-dev python-pyscard
python3-serial python3-cmd2 python3-construct python3-bidict
```

Appendix B: Configuration Files

1. epc.conf file

```
#####
                                srsEPC configuration file
#####

#####
# MME configuration
#
# mme_code:           8-bit MME code identifies the MME within a group.
# mme_group:         16-bit MME group identifier.
# tac:               16-bit Tracking Area Code.
# mcc:              Mobile Country Code
# mnc:              Mobile Network Code
# apn:              Set Access Point Name (APN)
# mme_bind_addr:    IP bind addr to listen for eNB S1-MME connections
# dns_addr:         DNS server address for the UEs
# encryption_algo: Preferred encryption algorithm for NAS layer
#                   (supported: EEA0 (default), EEA1, EEA2, EEA3)
# integrity_algo:   Preferred integrity protection algorithm for NAS
#                   (supported: EIA0 (rejected by most UEs), EIA1 (default), EIA2,
#                   EIA3)
# paging_timer:     Value of paging timer in seconds (T3413)
# request_imeisv:   Request UE's IMEI-SV in security mode command
#####
[mme]
mme_code = 0x1a
mme_group = 0x0001
tac = 0x0007
mcc = 001
mnc = 01
mme_bind_addr = 127.0.1.100
apn = srsapn
dns_addr = 8.8.8.8
encryption_algo = EEA0
integrity_algo = EIA1
paging_timer = 2
request_imeisv = false

#####
# HSS configuration
#
# db_file:          Location of .csv file that stores UEs information.
#
#####
[hss]
```

db_file = user_db.csv

```
#####
# SP-GW configuration
#
# gtpu_bind_addr:      GTP-U bind address.
# sgi_if_addr:        SGi TUN interface IP address.
# sgi_if_name:        SGi TUN interface name.
# max_paging_queue:  Maximum packets in paging queue (per UE).
#
#####
[spgw]
####gtpu_bind_addr = 127.0.1.100
gtpu_bind_addr = 147.83.105.216
sgi_if_addr = 172.16.0.1
sgi_if_name = srs_spgw_sgi
max_paging_queue = 100
#####
# PCAP configuration
#
# Packets are captured to file in the compact format decoded by
# the Wireshark s1ap dissector and with DLT 150.
# To use the dissector, edit the preferences for DLT_USER to
# add an entry with DLT=150, Payload Protocol=s1ap.
#
# enable:  Enable or disable the PCAP.
# filename: File name where to save the PCAP.
#
#####
[pcap]
enable = false
filename = /tmp/epc.pcap

#####
# Log configuration
#
# Log levels can be set for individual layers. "all_level" sets log
# level for all layers unless otherwise configured.
# Format: e.g. s1ap_level = info
#
# In the same way, packet hex dumps can be limited for each level.
# "all_hex_limit" sets the hex limit for all layers unless otherwise
# configured.
# Format: e.g. s1ap_hex_limit = 32
#
# Logging layers: nas, s1ap, mme_gtpc, spgw_gtpc, gtpu, spgw, hss, all
# Logging levels: debug, info, warning, error, none
#
```

```
# filename: File path to use for log output. Can be set to stdout
#          to print logs to standard output
#####
[log]
all_level = info
all_hex_limit = 32
filename = /tmp/epc.log

#nas_level = debug
#s1ap_level = debug
#mme_gtpc_level = debug
#spgw_gtpc_level = debug
#gtpu_level = debug
#spgw_level = debug
#hss_level = debug
```

2. enb.conf file

```
#####
srsENB configuration file
#####

#####
# eNB configuration
#
# enb_id:      20-bit eNB identifier.
# mcc:        Mobile Country Code
# mnc:        Mobile Network Code
# mme_addr:    IP address of MME for S1 connection
# gtp_bind_addr:  Local IP address to bind for GTP connection
# gtp_advertise_addr: IP address of eNB to advertise for DL GTP-U Traffic
# s1c_bind_addr:  Local IP address to bind for S1AP connection
# s1c_bind_port: Source port for S1AP connection (0 means any)
# n_prb:      Number of Physical Resource Blocks (6,15,25,50,75,100)
# tm:         Transmission mode 1-4 (TM1 default)
# nof_ports:   Number of Tx ports (1 port default, set to 2 for TM2/3/4)
#
#####
[enb]
enb_id = 0x19B
mcc = 001
mnc = 01
mme_addr = 127.0.1.100
gtp_bind_addr = 127.0.1.1
s1c_bind_addr = 127.0.1.1
s1c_bind_port = 0
```

```

n_prb = 50
#tm = 4
#nof_ports = 2

#####
# eNB configuration files
#
# sib_config: SIB1, SIB2 and SIB3 configuration file
# note: When enabling MBMS, use the sib.conf.mbsfn configuration file which #includes SIB13
# rr_config: Radio Resources configuration file
# rb_config: SRB/DRB configuration file
#####
[enb_files]
sib_config = sib.conf
rr_config = rr.conf
rb_config = rb.conf

#####
# RF configuration
#
# dl_earfcn: EARFCN code for DL (only valid if a single cell is configured in rr.conf)
# tx_gain: Transmit gain (dB).
# rx_gain: Optional receive gain (dB). If disabled, AGC if enabled
#
# Optional parameters:
# dl_freq: Override DL frequency corresponding to dl_earfcn
# ul_freq: Override UL frequency corresponding to dl_earfcn (must be set if
# dl_freq is set)
# device_name: Device driver family
# Supported options: "auto" (uses first driver found), "UHD", "bladeRF",
# "soapy", "zmq" or "Sideiq"
# device_args: Arguments for the device driver. Options are "auto" or any string.
# Default for UHD: "recv_frame_size=9232,send_frame_size=9232"
# Default for bladeRF: ""
# time_adv_nsamples: Transmission time advance (in number of samples) to
# compensate for RF delay from antenna to timestamp insertion.
# Default "auto". B210 USRP: 100 samples, bladeRF: 27
#####
[rf]
#dl_earfcn = 3350
tx_gain = 80
rx_gain = 40

#device_name = auto

# For best performance in 2x2 MIMO and >= 15 MHz use the following device_args #settings:
# USRP B210: num_recv_frames=64,num_send_frames=64
# And for 75 PRBs, also append ",master_clock_rate=15.36e6" to the device args

```



```
# For best performance when BW<5 MHz (25 PRB), use the following device_args #settings:
#   USRP B210: send_frame_size=512,recv_frame_size=512

#device_args = auto
#time_adv_nsamples = auto

# Example for ZMQ-based operation with TCP transport for I/Q samples
#device_name = zmq
#device_args =
fail_on_disconnect=true,tx_port=tcp://*:2000,rx_port=tcp://localhost:2001,id=enb,base_srate=23.04e
6

#####
# Packet capture configuration
#
# MAC-layer packets are captured to a file in the compact format which can
# be decoded by Wireshark. For decoding, use the UDP dissector and the UDP
# heuristic dissection. Edit the preferences (Edit > Preferences >
# Protocols > DLT_USER) for DLT_USER to add an entry for DLT=149 with
# Protocol=udp. Further, enable the heuristic dissection in UDP under:
# Analyze > Enabled Protocols > MAC-LTE > mac_lte_udp and MAC-NR > mac_nr_udp
# For more information see: https://wiki.wireshark.org/MAC-LTE
# Configuring this Wireshark preferences is needed for decoding the MAC PCAP
# files as well as for the live network capture option.
#
# Please note that this setting will by default only capture MAC
# frames on dedicated channels, and not SIB. You have to build with
# WRITE_SIB_PCAP enabled in srsenb/src/stack/mac/mac.cc if you want
# SIB to be part of the MAC pcap file.
#
# S1AP Packets are captured to a file in the compact format which can
# be decoded by the Wireshark s1ap dissector with DLT 150.
# To use the dissector, edit the preferences for DLT_USER to
# add an entry with DLT=150, Payload Protocol=s1ap.
#
# mac_enable: Enable MAC layer packet captures (true/false)
# mac_filename: File path to use for packet captures
# s1ap_enable: Enable or disable the PCAP.
# s1ap_filename: File name where to save the PCAP.
#
# mac_net_enable: Enable MAC layer packet captures sent over the network (true/false default: false)
# bind_ip: Bind IP address for MAC network trace (default: "0.0.0.0")
# bind_port: Bind port for MAC network trace (default: 5687)
# client_ip: Client IP address for MAC network trace (default: "127.0.0.1")
# client_port Client IP address for MAC network trace (default: 5847)
#####
[pcap]
```

```
enable = false
filename = /tmp/enb.pcap
s1ap_enable = false
s1ap_filename = /tmp/enb_s1ap.pcap
```

```
mac_net_enable = false
bind_ip = 0.0.0.0
bind_port = 5687
client_ip = 127.0.0.1
client_port = 5847
```

```
#####
```

```
# Log configuration
```

```
#
```

```
# Log levels can be set for individual layers. "all_level" sets log
# level for all layers unless otherwise configured.
```

```
# Format: e.g. phy_level = info
```

```
#
```

```
# In the same way, packet hex dumps can be limited for each level.
```

```
# "all_hex_limit" sets the hex limit for all layers unless otherwise
# configured.
```

```
# Format: e.g. phy_hex_limit = 32
```

```
#
```

```
# Logging layers: rf, phy, phy_lib, mac, rlc, pdcp, rrc, gtpu, s1ap, stack, all
```

```
# Logging levels: debug, info, warning, error, none
```

```
#
```

```
# filename: File path to use for log output. Can be set to stdout
```

```
# to print logs to standard output
```

```
# file_max_size: Maximum file size (in kilobytes). When passed, multiple files are
```

```
# created.
```

```
# If set to negative, a single log file will be created.
```

```
#####
```

```
[log]
```

```
all_level = warning
```

```
all_hex_limit = 32
```

```
filename = /tmp/enb.log
```

```
file_max_size = -1
```

```
[gui]
```

```
enable = true
```

```
#####
```

```
# Scheduler configuration options
```

```
#
```

```
# sched_policy: User MAC scheduling policy (E.g. time_rr, time_pf)
```

```
# min_aggr_level: Optional minimum aggregation level index (l=log2(L) can be 0, 1, #2 or 3)
```

```
# max_aggr_level: Optional maximum aggregation level index (l=log2(L) can be 0, 1, #2 or 3)
```

```

# adaptive_aggr_level: Boolean flag to enable/disable adaptive aggregation level #based on target
BLER
# pdsch_mcs:    Optional fixed PDSCH MCS (ignores reported CQIs if specified)
# pdsch_max_mcs:  Optional PDSCH MCS limit
# pusch_mcs:    Optional fixed PUSCH MCS (ignores reported CQIs if specified)
# pusch_max_mcs:  Optional PUSCH MCS limit
# min_nof_ctrl_symbols: Minimum number of control symbols
# max_nof_ctrl_symbols: Maximum number of control symbols
# pucch_multiplex_enable: Allow PUCCH HARQ to collide with PUSCH and other #PUCCH
# pucch_harq_max_rb: Maximum number of RB to be used for PUCCH on the edges of #the grid.
#           If defined and greater than 0, the scheduler will avoid DL PDCCH #allocations if
#           PUCCH HARQ falls outside this region
# target_bler:   Target BLER (in decimal) to achieve via adaptive link
# max_delta_dl_cqi: Maximum shift in CQI for adaptive DL link
# max_delta_ul_snr: Maximum shift in UL SNR for adaptive UL link
# adaptive_dl_mcs_step_size: Step size or learning rate used in adaptive DL MCS link
# adaptive_ul_mcs_step_size: Step size or learning rate used in adaptive UL MCS link
# min_tpc_tti_interval: Minimum TTI interval between TPCs different than 1
# ul_snr_avg_alpha: Exponential Average alpha coefficient used in estimation of UL #SNR
# init_ul_snr_value: Initial UL SNR value used for computing MCS in the first UL grant
# init_dl_cqi:   DL CQI value used before any CQI report is available to the eNB
# max_sib_coderate: Upper bound on SIB and RAR grants coderate
# pdccch_cqi_offset: CQI offset in derivation of PDCCH aggregation level
# nr_pdsch_mcs:  Optional fixed NR PDSCH MCS (ignores reported CQIs if #specified)
# nr_pusch_mcs:  Optional fixed NR PUSCH MCS (ignores reported CQIs if #specified)
#
##### [scheduler]
#policy = time_pf
#policy_args = 2
#min_aggr_level = 0
#max_aggr_level = 3
#adaptive_aggr_level = false
#pdsch_mcs = -1
#pdsch_max_mcs = -1
#pusch_mcs = -1
#pusch_max_mcs = 16
#min_nof_ctrl_symbols = 1
#max_nof_ctrl_symbols = 3
#pucch_multiplex_enable = false
#pucch_harq_max_rb = 0
#target_bler = 0.05
#max_delta_dl_cqi = 5
#max_delta_ul_snr = 5
#adaptive_dl_mcs_step_size = 0.001
#adaptive_ul_mcs_step_size = 0.001
#min_tpc_tti_interval = 1
#ul_snr_avg_alpha=0.05
#init_ul_snr_value=5

```

```

#init_dl_cqi=5
#max_sib_coderate=0.3
#pdcch_cqi_offset=0
#nr_pdsch_mcs=28
#nr_pusch_mcs=28

#####
# eMBMS configuration options
#
# enable:      Enable MBMS transmission in the eNB
# m1u_multiaddr: Multicast address the M1-U socket will register to
# m1u_if_addr:  Address of the interface the M1-U interface will listen to for
#               multicast packets
# mcs:         Modulation and Coding scheme for MBMS traffic
#
#####
[embms]
#enable = false
#m1u_multiaddr = 239.255.0.1
#m1u_if_addr = 127.0.1.201
#mcs = 20

#####
# Channel emulator options:
# enable:      Enable/disable internal Downlink/Uplink channel emulator
#
# -- AWGN Generator
# awgn.enable: Enable/disable AWGN generator
# awgn.snr:    Target SNR in dB
#
# -- Fading emulator
# fading.enable: Enable/disable fading simulator
# fading.model: Fading model + maximum doppler (E.g. none, epa5, eva70, etu300, etc)
#
# -- Delay Emulator  delay(t) = delay_min + (delay_max - delay_min) * (1 +
#               sin(2pi*t/period)) / 2
#               Maximum speed [m/s]: (delay_max - delay_min) * pi * 300 /
#               period
# delay.enable:  Enable/disable delay simulator
# delay.period_s: Delay period in seconds
# delay.init_time_s: Delay initial time in seconds
# delay.maximum_us: Maximum delay in microseconds
# delay.minumum_us: Minimum delay in microseconds
#
# -- Radio-Link Failure (RLF) Emulator
# rlf.enable:    Enable/disable RLF simulator
# rlf.t_on_ms:   Time for On state of the channel (ms)
# rlf.t_off_ms:  Time for Off state of the channel (ms)

```

```
#
# -- High Speed Train Doppler model simulator
# hst.enable:    Enable/disable HST simulator
# hst.period_s:  HST simulation period in seconds
# hst.fd_hz:     Doppler frequency in Hz
# hst.init_time_s: Initial time in seconds
#####
[channel.dl]
#enable    = false

[channel.dl.awgn]
#enable    = false
#snr       = 30

[channel.dl.fading]
#enable    = false
#model     = none

[channel.dl.delay]
#enable    = false
#period_s  = 3600
#init_time_s = 0
#maximum_us = 100
#minimum_us = 10

[channel.dl.rlf]
#enable    = false
#t_on_ms   = 10000
#t_off_ms  = 2000

[channel.dl.hst]
#enable    = false
#period_s  = 7.2
#fd_hz     = 750.0
#init_time_s = 0.0

[channel.ul]
#enable    = false

[channel.ul.awgn]
#enable    = false
#n0        = -30

[channel.ul.fading]
#enable    = false
#model     = none

[channel.ul.delay]
```

```
#enable = false
#period_s = 3600
#init_time_s = 0
#maximum_us = 100
#minimum_us = 10
```

```
[channel.ul.rlf]
#enable = false
#t_on_ms = 10000
#t_off_ms = 2000
```

```
[channel.ul.hst]
#enable = false
#period_s = 7.2
#fd_hz = -750.0
#init_time_s = 0.0
```

```
#####
# Expert configuration options
#
# pusch_max_its: Maximum number of turbo decoder iterations (default: 4)
# nr_pusch_max_its: Maximum number of LDPC iterations for NR (Default 10)
# pusch_8bit_decoder: Use 8-bit for LLR representation and turbo decoder trellis
# computation (experimental)
# nof_phy_threads: Selects the number of PHY threads (maximum: 4, minimum: 1, # default: 3)
# metrics_period_secs: Sets the period at which metrics are requested from the eNB
# metrics_csv_enable: Write eNB metrics to CSV file.
# metrics_csv_filename: File path to use for CSV metrics
# report_json_enable: Write eNB report to JSON file (default: disabled)
# report_json_filename: Report JSON filename (default: /tmp/enb_report.json)
# report_json_asn1_oct: Prints ASN1 messages encoded as an octet string instead of
# plain text in the JSON report file
# alarms_log_enable: Enable Alarms logging (default: disabled)
# alarms_filename: Alarms logging filename (default: /tmp/alarms.log)
# tracing_enable: Write source code tracing information to a file
# tracing_filename: File path to use for tracing information
# tracing_buffcapacity: Maximum capacity in bytes the tracing framework can store
# stdout_ts_enable: Prints once per second the timestamp into stdout
# pregenerate_signals: Pregenerate uplink signals after attach. Improves CPU
# performance
# tx_amplitude: Transmit amplitude factor (set 0-1 to reduce PAPR)
# rrc_inactivity_timer Inactivity timeout used to remove UE context from RRC (in
# milliseconds)
# max_mac_dl_kos: Maximum number of consecutive KOs in DL before triggering # the UE's release
# (default: 100)
# max_mac_ul_kos: Maximum number of consecutive KOs in UL before triggering # the UE's release
# (default: 100)
# max_prach_offset_us: Maximum allowed RACH offset (in us)
```

```
# nof_prealloc_ues: Number of UE memory resources to preallocate during eNB
# initialization for faster UE creation (default: 8)
# rlf_release_timer_ms: Time taken by eNB to release UE context after it detects an
# RLF
# eea_pref_list: Ordered preference list for the selection of encryption algorithm # (EEA) (default:
EEA0, EEA2, EEA1)
# eia_pref_list: Ordered preference list for the selection of integrity algorithm
# (EIA) (default: EIA2, EIA1, EIA0)
# gtpu_tunnel_timeout: Time that GTPU takes to release indirect forwarding tunnel # since the last
received GTPU PDU (0 for no timer)
# ts1_reloc_prep_timeout: S1AP TS 36.413 TS1RelocPrep Expiry Timeout value in
# milliseconds
# ts1_reloc_overall_timeout: S1AP TS 36.413 TS1RelocOverall Expiry Timeout value # in milliseconds
# rlf_release_timer_ms: Time taken by eNB to release UE context after it detects a
# RLF
# rlf_min_ul_snr_estim: SNR threshold in dB below which the enb is notified with RLF # ko
#
#####
[expert]
#pusch_max_its = 8 # These are half iterations
#nr_pusch_max_its = 10
#pusch_8bit_decoder = false
#nof_phy_threads = 3
#metrics_period_secs = 1
#metrics_csv_enable = false
#metrics_csv_filename = /tmp/enb_metrics.csv
#report_json_enable = true
#report_json_filename = /tmp/enb_report.json
#report_json_asn1_oct = false
#alarms_log_enable = true
#alarms_filename = /tmp/enb_alarms.log
#tracing_enable = true
#tracing_filename = /tmp/enb_tracing.log
#tracing_buffcapacity = 1000000
#stdout_ts_enable = false
#pregenerate_signals = false
#tx_amplitude = 0.6
#rrc_inactivity_timer = 30000
#max_mac_dl_kos = 100
#max_mac_ul_kos = 100
#max_prach_offset_us = 30
#nof_prealloc_ues = 8
#rlf_release_timer_ms = 4000
#lcid_padding = 3
#eea_pref_list = EEA0, EEA2, EEA1
#eia_pref_list = EIA2, EIA1, EIA0
#gtpu_tunnel_timeout = 0
#extended_cp = false
```

```
#ts1_reloc_prep_timeout = 10000
#ts1_reloc_overall_timeout = 10000
#rlf_release_timer_ms = 4000
#rlf_min_ul_snr_estim = -2
```

3. user_db.csv file

```
#
# .csv to store UE's information in HSS
# Kept in the following format: "Name,Auth,IMSI,Key,OP_Type,OP/OPc,AMF,SQN,QCI,IP_alloc"
#
# Name:           Human readable name to help distinguish UE's. Ignored by the HSS
# Auth:           Authentication algorithm used by the UE. Valid algorithms are XOR
#                 (xor) and MILENAGE (mil)
# IMSI:           UE's IMSI value
# Key:            UE's key, where other keys are derived from. Stored in hexadecimal
# OP_Type:        Operator's code type, either OP or OPc
# OP/OPc:         Operator Code/Cyphered Operator Code, stored in hexadecimal
# AMF:            Authentication management field, stored in hexadecimal
# SQN:            UE's Sequence number for freshness of the authentication
# QCI:            QoS Class Identifier for the UE's default bearer.
# IP_alloc:       IP allocation strategy for the SPGW.
#                 With 'dynamic' the SPGW will automatically allocate IPs
#                 With a valid IPv4 (e.g. '172.16.0.2') the UE will have a statically assigned
#                 IP.
#
# Note: Lines starting by '#' are ignored and will be overwritten
ue1,xor,001010123456789,00112233445566778899aabbccddeeff,opc,63bfa50ee6523365ff14c1f45f
88737d,9001,000000001234,7,dynamic
ue2,mil,001010123456780,00112233445566778899aabbccddeeff,opc,63bfa50ee6523365ff14c1f45f
88737d,8000,000000001234,7,dynamic
```


Appendix C: Complete Measurement Logs

1. Logs for PRB=6

```

usuariogrcm@srsdesktop2:~/srsRAN/srsenb$ sudo srsenb enb.conf
--- Software Radio Systems LTE eNodeB ---

Reading configuration file enb.conf...
Couldn't open sib.conf, trying /root/.config/srsran/sib.conf
Couldn't open rr.conf, trying /root/.config/srsran/rr.conf
Couldn't open rb.conf, trying /root/.config/srsran/rb.conf

Built in Release mode using commit 5275f3336 on branch master.

ERROR: Invalid PRACH configuration - prach=(4, 10) does not fit into the eNB PRBs=(0, 6).
Consider changing the "prach_freq_offset" value to 0 in the sib.conf file when using 6 PRBs.
Opening 1 channels in RF device=UHD with args=default
Available RF device list: UHD zmq
[INFO] [UHD] linux; GNU C++ version 9.4.0; Boost_107100; UHD_4.3.0.0-15-g5333d3d1
[INFO] [LOGGING] Fastpath logging disabled at runtime.
Opening USRP channels=1, args: type=b200,master_clock_rate=23.04e6
[INFO] [UHD RF] RF UHD Generic instance constructed
[INFO] [B200] Detected Device: B210
[INFO] [B200] Operating over USB 3.
[INFO] [B200] Initialize CODEC control...
[INFO] [B200] Initialize Radio control...
[INFO] [B200] Performing register loopback test...
[INFO] [B200] Register loopback test passed
[INFO] [B200] Performing register loopback test...
[INFO] [B200] Register loopback test passed
[INFO] [B200] Asking for clock rate 23.040000 MHz...
[INFO] [B200] Actually got clock rate 23.040000 MHz.

==== eNodeB started ====
Type <t> to view trace
Setting frequency: DL=2680.0 Mhz, UL=2560.0 MHz for cc_idx=0 nof_prb=6
Starting plot for worker_id=0
Creating plot window 'srsENB PCI 1'...
QStandardPaths: XDG_RUNTIME_DIR not set, defaulting to '/tmp/runtime-root'
RACH: tti=9801, cc=0, preamble=25, temp_crnti=0x46
t
Enter t to stop trace.

-----DL-----
rat rnti cqi ri mcs brate ok nok (%) | pusch pucch phr mcs brate ok nok (%) bsr
lte 46 15 0 0 0 0 0 0% | n/a 3.2 0 0 0 0 0 0% 0.0
lte 46 15 0 0 32 2 3 60% | n/a 0.5 0 0 0 0 0 0% 0.0
lte 46 15 0 0 0 0 0 0% | n/a 1.2 0 0 0 0 0 0% 0.0
lte 46 15 0 0 0 0 0 0% | n/a 0.1 0 0 0 0 0 0% 0.0
lte 46 15 0 0 0 0 0 0% | n/a 1.1 0 0 0 0 0 0% 0.0
lte 46 n/a 0 0 0 0 0 0% | n/a -4.6 0 0 0 0 0 0% 0.0
lte 46 10 0 0 0 0 0 0% | n/a -6.8 0 0 0 0 0 0% 0.0
lte 46 n/a 0 0 0 0 0 0% | n/a -6.2 0 0 0 0 0 0% 0.0
lte 46 n/a 0 0 0 0 0 0% | n/a -6.6 0 0 0 0 0 0% 0.0
lte 46 n/a 0 0 0 0 0 0% | n/a -7.8 0 0 0 0 0 0% 0.0
lte 46 n/a 0 0 0 0 0 0% | n/a -5.8 0 0 0 0 0 0% 0.0

-----DL-----
rat rnti cqi ri mcs brate ok nok (%) | pusch pucch phr mcs brate ok nok (%) bsr
lte 46 n/a 0 0 0 0 0 0% | n/a -6.1 0 0 0 0 0 0% 0.0
lte 46 n/a 0 0 0 0 0 0% | n/a -6.5 0 0 0 0 0 0% 0.0
lte 46 3 0 0 0 0 0 0% | n/a -6.3 0 0 0 0 0 0% 0.0
lte 46 n/a 0 0 0 0 0 0% | n/a -5.8 0 0 0 0 0 0% 0.0
RACH: tti=4981, cc=0, preamble=48, offset=1, temp_crnti=0x47
User 0x47 connected
lte 46 n/a 0 0 0 0 0 0% | n/a -6.1 0 0 0 0 0 0% 0.0
lte 47 14 0 12 4.6k 16 0 0% | 8.1 4.7 36 4 13k 45 0 0% 0.0
lte 46 12 0 0 0 0 0 0% | n/a -8.1 0 0 0 0 0 0% 0.0
lte 47 15 0 20 124k 49 0 0% | 6.9 7.0 35 3 32k 110 0 0% 0.0
lte 46 n/a 0 0 0 0 0 0% | n/a -6.3 0 0 0 0 0 0% 0.0
lte 47 15 0 0 0 0 0 0% | n/a 0.6 0 0 0 0 0 0% 0.0
lte 46 n/a 0 0 0 0 0 0% | n/a -5.6 0 0 0 0 0 0% 0.0
lte 47 15 0 0 0 0 0 0% | n/a -0.8 0 0 0 0 0 0% 0.0
lte 46 n/a 0 0 0 0 0 0% | n/a -7.0 0 0 0 0 0 0% 0.0
lte 47 15 0 0 0 0 0 0% | n/a 1.6 0 0 0 0 0 0% 0.0
lte 46 n/a 0 0 0 0 0 0% | n/a -6.5 0 0 0 0 0 0% 0.0
lte 47 15 0 0 0 0 0 0% | n/a 0.9 0 0 0 0 0 0% 0.0
lte 46 n/a 0 0 0 0 0 0% | n/a -7.3 0 0 0 0 0 0% 0.0
lte 47 15 0 0 0 0 0 0% | n/a 0.3 0 0 0 0 0 0% 0.0

```

		DL							UL								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	46	10	0	0	0	0	0	0%	n/a	-7.2	0	0	0	0	0	0%	0.0
lte	47	15	0	19	23k	31	1	3%	4.9	2.6	35	2	32k	179	0	0%	0.0
lte	46	n/a	0	0	0	0	0	0%	n/a	-5.8	0	0	0	0	0	0%	0.0
lte	47	15	0	19	30k	65	2	2%	5.1	5.1	34	2	70k	365	0	0%	0.0
lte	46	1	0	0	0	0	0	0%	n/a	-6.6	0	0	0	0	0	0%	0.0
lte	47	15	0	26	2.6M	688	20	2%	5.5	9.4	34	3	181k	740	0	0%	752
lte	46	n/a	0	0	0	0	0	0%	n/a	-6.5	0	0	0	0	0	0%	0.0
lte	47	15	0	26	3.4M	873	27	3%	5.5	9.6	34	3	209k	829	0	0%	752
lte	46	n/a	0	0	0	0	0	0%	n/a	-7.2	0	0	0	0	0	0%	0.0
lte	47	15	0	26	3.4M	883	17	1%	5.7	9.9	34	5	241k	636	0	0%	768
lte	46	n/a	0	0	0	0	0	0%	n/a	-8.1	0	0	0	0	0	0%	0.0
lte	47	15	0	26	3.4M	887	13	1%	6.3	10.4	34	7	238k	504	0	0%	1.02k
lte	46	n/a	0	0	0	0	0	0%	n/a	-8.1	0	0	0	0	0	0%	0.0
lte	47	15	0	26	3.5M	893	7	0%	6.8	11.2	35	8	268k	494	2	0%	0.0
Disconnecting rnti=0x46.																	
lte	47	15	0	26	3.0M	838	62	6%	5.2	7.8	35	6	224k	491	4	0%	0.0
lte	47	15	0	25	2.8M	839	61	6%	5.1	8.3	35	7	206k	441	12	2%	27.0
lte	47	15	0	25	2.8M	852	48	5%	5.1	9.2	35	7	219k	462	15	3%	0.0
lte	47	15	0	25	3.2M	899	0	0%	7.8	12.3	33	11	264k	366	5	1%	0.0

		DL							UL								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	26	3.5M	900	0	0%	8.6	13.2	33	12	271k	346	13	3%	0.0
lte	47	15	0	26	2.0M	544	2	0%	10.7	15.4	34	13	232k	243	9	3%	0.0
lte	47	15	0	18	116k	146	0	0%	25.1	26.8	35	22	1.6M	822	0	0%	151k
lte	47	15	0	18	107k	169	0	0%	25.1	n/a	35	23	1.8M	900	0	0%	128k
lte	47	15	0	19	103k	175	0	0%	25.8	n/a	34	23	1.8M	900	0	0%	95.1k
lte	47	15	0	19	93k	183	0	0%	26.1	n/a	34	23	1.8M	899	0	0%	112k
lte	47	15	0	19	89k	165	0	0%	26.5	n/a	33	23	1.8M	900	0	0%	111k
lte	47	15	0	19	62k	123	0	0%	26.7	n/a	33	23	1.8M	900	0	0%	112k
lte	47	15	0	18	62k	122	0	0%	26.6	n/a	33	23	1.8M	901	0	0%	128k
lte	47	15	0	19	75k	139	0	0%	27.4	n/a	30	23	1.8M	900	0	0%	111k
lte	47	15	0	19	67k	135	0	0%	27.4	n/a	30	23	1.8M	900	0	0%	127k

		DL							UL								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	18	79k	145	0	0%	27.0	n/a	32	23	1.8M	899	0	0%	94.0k
lte	47	15	0	18	83k	155	0	0%	26.7	n/a	32	23	1.8M	900	0	0%	111k
lte	47	15	0	18	125k	141	0	0%	16.2	n/a	31	20	1.5M	892	8	0%	96.8k
lte	47	15	0	19	59k	119	0	0%	12.1	n/a	34	16	1.2M	896	4	0%	67.3k
lte	47	15	0	19	59k	122	0	0%	12.4	n/a	34	17	1.2M	899	2	0%	71.5k
lte	47	15	0	17	50k	104	0	0%	11.3	n/a	34	16	1.1M	894	5	0%	41.9k
lte	47	15	0	18	80k	90	0	0%	12.1	n/a	33	16	1.1M	891	9	1%	44.7k
lte	47	15	0	20	115k	124	0	0%	24.2	n/a	33	22	1.8M	899	1	0%	30.0k
lte	47	15	0	19	112k	67	0	0%	26.0	19.5	34	22	336k	173	0	0%	0.0
lte	47	15	0	24	332k	96	0	0%	25.7	20.7	34	20	32k	20	0	0%	0.0
lte	47	15	0	16	13k	11	0	0%	28.0	11.7	34	23	14k	7	0	0%	0.0

		DL							UL								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	7	1.6k	6	0	0%	26.5	7.3	34	23	8.0k	4	0	0%	0.0
lte	47	15	0	0	832	2	0	0%	25.4	6.4	35	23	4.0k	2	0	0%	0.0
lte	47	15	0	13	10k	11	0	0%	25.0	10.9	35	22	24k	13	0	0%	0.0
lte	47	15	0	12	832	2	0	0%	n/a	4.9	35	0	4.0k	2	0	0%	0.0
lte	47	15	0	0	832	2	0	0%	24.4	4.6	36	23	4.0k	2	0	0%	0.0
lte	47	15	0	12	833	2	0	0%	22.2	3.9	39	23	4.0k	2	0	0%	0.0
lte	47	15	0	0	831	2	0	0%	21.8	3.2	39	23	4.0k	2	0	0%	0.0
lte	47	15	0	12	10k	12	0	0%	22.0	7.2	39	22	23k	12	0	0%	0.0
lte	47	15	0	25	794k	216	0	0%	22.5	18.6	39	21	53k	31	0	0%	0.0
lte	47	15	0	26	2.4M	638	0	0%	22.5	20.2	39	21	118k	72	0	0%	0.0
lte	47	15	0	26	3.3M	856	0	0%	22.3	18.2	39	21	106k	63	0	0%	0.0

		DL							UL								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	26	3.5M	899	0	0%	22.5	23.1	39	20	108k	66	0	0%	0.0
lte	47	15	0	26	3.5M	901	0	0%	22.6	25.0	39	19	130k	94	0	0%	0.0
lte	47	15	0	26	3.5M	900	0	0%	22.6	25.1	39	19	128k	97	0	0%	0.0
lte	47	15	0	26	3.5M	900	0	0%	22.9	24.9	39	19	140k	107	0	0%	0.0
lte	47	15	0	26	3.5M	900	0	0%	22.6	24.3	39	19	167k	124	0	0%	0.0
lte	47	15	0	26	3.5M	900	0	0%	22.5	23.5	38	21	103k	58	0	0%	0.0
lte	47	15	0	26	3.5M	899	0	0%	22.9	22.4	38	20	207k	139	0	0%	0.0
lte	47	15	0	26	2.7M	710	0	0%	22.7	21.0	38	21	209k	120	0	0%	6.00k
lte	47	15	0	19	56k	129	0	0%	22.2	n/a	38	23	1.8M	900	0	0%	10.3k
lte	47	15	0	19	43k	91	0	0%	21.9	n/a	39	23	1.8M	901	0	0%	22.9k
lte	47	15	0	17	42k	100	0	0%	21.9	n/a	39	23	1.8M	900	0	0%	38.4k

		DL							UL								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	18	51k	102	0	0%	21.7	n/a	39	23	1.8M	899	0	0%	48.5k
lte	47	15	0	18	43k	100	0	0%	21.8	n/a	39	23	1.8M	900	0	0%	70.6k
lte	47	15	0	19	42k	88	0	0%	21.6	n/a	39	23	1.8M	900	0	0%	108k

lte	47	15	0	18	72k	125	0	0%	22.1	n/a	38	23	1.8M	900	0	0%	109k
lte	47	15	0	18	92k	139	0	0%	21.8	n/a	38	23	1.8M	901	0	0%	111k
lte	47	15	0	20	66k	134	0	0%	21.8	n/a	39	23	1.8M	900	0	0%	94.3k
lte	47	15	0	18	58k	111	0	0%	21.8	n/a	39	23	1.8M	899	0	0%	96.3k
lte	47	15	0	18	42k	100	0	0%	21.9	n/a	38	23	1.8M	900	0	0%	95.6k
lte	47	15	0	19	43k	96	0	0%	22.3	n/a	38	23	1.8M	900	0	0%	92.5k
lte	47	15	0	17	43k	100	0	0%	22.1	n/a	38	23	1.8M	900	0	0%	95.3k
lte	47	15	0	17	42k	98	0	0%	22.5	n/a	38	23	1.8M	900	0	0%	5.74k

-----DL-----									-----UL-----								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	18	20k	15	0	0%	22.6	4.1	38	21	63k	34	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	4.1	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	4.4	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	4.3	0	0	0	0	0	0%	0.0
lte	47	15	0	14	9.2k	8	0	0%	19.8	7.0	40	22	19k	10	0	0%	0.0
lte	47	15	0	0	56	1	0	0%	21.6	5.1	40	23	2.0k	1	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	2.8	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	2.3	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	2.6	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	2.4	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	2.3	0	0	0	0	0	0%	0.0

-----DL-----									-----UL-----								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	0	0	0	0	0%	n/a	1.9	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	3.2	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	4.7	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	3.5	0	0	0	0	0	0%	0.0
lte	47	15	0	0	112	2	0	0%	21.0	2.8	40	23	4.0k	2	0	0%	0.0
lte	47	15	0	10	1.4k	4	0	0%	21.2	5.4	40	23	4.0k	2	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	2.7	0	0	0	0	0	0%	0.0

Stopping ..
 --- exiting ---
 usuariogr@msrdesktop2:~/srsRAN/srsenb\$

2. Logs for PRB=15

usuariogr@msrdesktop2:~/srsRAN/srsenb\$ sudo srsenb enb.conf
 --- Software Radio Systems LTE eNodeB ---

Reading configuration file enb.conf...
 Couldn't open sib.conf, trying /root/.config/srsran/sib.conf
 Couldn't open rr.conf, trying /root/.config/srsran/rr.conf
 Couldn't open rb.conf, trying /root/.config/srsran/rb.conf

Built in Release mode using commit 5275f3336 on branch master.

Opening 1 channels in RF device=UHD with args=default
 Available RF device list: UHD zmq
 [INFO] [UHD] linux; GNU C++ version 9.4.0; Boost_107100; UHD_4.3.0.0-15-g5333d3d1
 [INFO] [LOGGING] Fastpath logging disabled at runtime.
 Opening USRP channels=1, args: type=b200,master_clock_rate=23.04e6
 [INFO] [UHD RF] RF UHD Generic instance constructed
 [INFO] [B200] Detected Device: B210
 [INFO] [B200] Operating over USB 3.
 [INFO] [B200] Initialize CODEC control...
 [INFO] [B200] Initialize Radio control...
 [INFO] [B200] Performing register loopback test...
 [INFO] [B200] Register loopback test passed
 [INFO] [B200] Performing register loopback test...
 [INFO] [B200] Register loopback test passed
 [INFO] [B200] Asking for clock rate 23.040000 MHz...
 [INFO] [B200] Actually got clock rate 23.040000 MHz.

==== eNodeB started ====
 Type <t> to view trace
 Setting frequency: DL=2680.0 Mhz, UL=2560.0 MHz for cc_idx=0 nof_prb=15
 Starting plot for worker_id=0
 Creating plot window 'srsENB PCI 1'...
 QStandardPaths: XDG_RUNTIME_DIR not set, defaulting to '/tmp/runtime-root'
 t
 Enter t to stop trace.
 RACH: tti=991, cc=0, preamble=11, offset=1, temp_crnti=0x46

-----DL-----									-----UL-----								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr

lte	46	14	0	4	1.7k	3	0	0%	20.9	8.3	28	7	18k	5	0	0%	0.0
lte	46	14	0	0	56	1	0	0%	26.9	-1.0	27	17	3.9k	1	0	0%	0.0
lte	46	15	0	0	0	0	0	0%	n/a	-0.2	0	0	0	0	0	0%	0.0
lte	46	15	0	0	0	0	0	0%	n/a	-2.1	0	0	0	0	0	0%	0.0
lte	46	15	0	0	0	0	0	0%	n/a	1.7	0	0	0	0	0	0%	0.0
lte	46	15	0	0	0	0	0	0%	n/a	0.8	0	0	0	0	0	0%	0.0
lte	46	15	0	0	0	0	0	0%	n/a	1.2	0	0	0	0	0	0%	0.0
lte	46	15	0	0	0	0	0	0%	n/a	2.5	0	0	0	0	0	0%	0.0
lte	46	14	0	0	0	0	0	0%	n/a	3.1	0	0	0	0	0	0%	0.0
lte	46	14	0	0	0	0	0	0%	n/a	3.5	0	0	0	0	0	0%	0.0
lte	46	14	0	0	0	0	0	0%	n/a	2.6	0	0	0	0	0	0%	0.0

DL									UL								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	46	13	0	0	0	0	0	0%	n/a	2.0	0	0	0	0	0	0%	0.0
lte	46	14	0	0	0	0	0	0%	n/a	1.9	0	0	0	0	0	0%	0.0
lte	46	15	0	0	0	0	0	0%	n/a	2.3	0	0	0	0	0	0%	0.0
lte	46	15	0	0	0	0	0	0%	n/a	1.8	0	0	0	0	0	0%	0.0
lte	46	15	0	0	0	0	0	0%	n/a	3.4	0	0	0	0	0	0%	0.0
lte	46	15	0	0	0	0	0	0%	n/a	-0.9	0	0	0	0	0	0%	0.0
lte	46	n/a	0	0	0	0	0	0%	n/a	-7.1	0	0	0	0	0	0%	0.0
lte	46	2	0	0	0	0	3	100%	n/a	-7.1	0	0	0	0	0	0%	0.0
lte	46	n/a	0	0	0	0	0	0%	n/a	-5.4	0	0	0	0	0	0%	0.0
lte	46	n/a	0	0	0	0	0	0%	n/a	-6.3	0	0	0	0	0	0%	0.0
lte	46	n/a	0	0	0	0	0	0%	n/a	-5.3	0	0	0	0	0	0%	0.0

DL									UL								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	46	15	0	0	0	0	3	100%	n/a	-6.7	0	0	0	0	0	0%	0.0
lte	46	n/a	0	0	0	0	0	0%	n/a	-7.3	0	0	0	0	0	0%	0.0
lte	46	n/a	0	0	0	0	0	0%	n/a	-7.0	0	0	0	0	0	0%	0.0
lte	46	n/a	0	0	0	0	0	0%	n/a	-6.2	0	0	0	0	0	0%	0.0
RACH: tti=6391, cc=0, preamble=4, offset=1, temp_crnti=0x47																	
lte	46	n/a	0	0	0	0	0	0%	n/a	-7.4	0	0	0	0	0	0%	0.0
lte	47	14	0	6	2.5k	4	0	0%	29.0	11.0	28	13	36k	7	0	0%	0.0
User 0x47 connected																	
lte	46	n/a	0	0	0	0	0	0%	n/a	-5.7	0	0	0	0	0	0%	0.0
lte	47	14	0	5	2.5k	11	0	0%	26.2	8.7	29	22	29k	7	0	0%	0.0
lte	46	n/a	0	0	0	0	0	0%	n/a	-7.5	0	0	0	0	0	0%	0.0
lte	47	15	0	19	180k	30	0	0%	26.3	14.7	32	22	58k	14	0	0%	0.0
lte	46	n/a	0	0	0	0	0	0%	n/a	-6.6	0	0	0	0	0	0%	0.0
lte	47	15	0	11	66k	44	0	0%	26.5	20.3	32	22	183k	42	0	0%	0.0
lte	46	n/a	0	0	0	0	0	0%	n/a	-7.4	0	0	0	0	0	0%	0.0
lte	47	14	0	11	65k	48	0	0%	28.5	23.1	28	22	171k	39	0	0%	0.0
lte	46	n/a	0	0	0	0	0	0%	n/a	-6.2	0	0	0	0	0	0%	0.0
lte	47	15	0	8	27k	34	0	0%	28.6	19.8	28	22	95k	23	0	0%	0.0
lte	46	n/a	0	0	0	0	0	0%	n/a	-5.7	0	0	0	0	0	0%	0.0
lte	47	15	0	13	74k	43	0	0%	28.6	21.8	28	22	106k	27	0	0%	0.0

DL									UL								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	46	11	0	0	0	0	3	100%	n/a	-6.4	0	0	0	0	0	0%	0.0
lte	47	15	0	11	76k	44	0	0%	28.5	22.7	30	22	112k	27	0	0%	0.0
lte	46	n/a	0	0	0	0	0	0%	n/a	-8.1	0	0	0	0	0	0%	0.0
lte	47	15	0	13	54k	66	0	0%	24.6	23.7	29	22	149k	36	0	0%	0.0
lte	46	n/a	0	0	0	0	0	0%	n/a	-7.2	0	0	0	0	0	0%	0.0
lte	47	14	0	17	376k	103	0	0%	24.8	24.4	30	20	229k	66	0	0%	0.0
lte	46	n/a	0	0	0	0	0	0%	n/a	-14.2	0	0	0	0	0	0%	0.0
lte	47	15	0	27	10M	945	0	0%	26.3	29.2	30	21	476k	114	0	0%	251
lte	46	n/a	0	0	0	0	0	0%	n/a	-13.5	0	0	0	0	0	0%	0.0
lte	47	15	0	27	11M	999	0	0%	27.2	29.7	30	21	573k	126	0	0%	0.0
lte	46	13	0	0	0	0	3	100%	n/a	-12.5	0	0	0	0	0	0%	0.0
lte	47	15	0	27	11M	1001	0	0%	27.4	29.7	30	21	564k	143	0	0%	0.0
lte	46	4	0	0	0	0	3	100%	n/a	-13.9	0	0	0	0	0	0%	0.0
lte	47	15	0	27	11M	999	0	0%	27.3	29.7	29	22	435k	104	0	0%	0.0
Disconnecting rnti=0x46.																	
lte	47	15	0	27	11M	985	0	0%	27.7	29.6	30	21	348k	99	0	0%	0.0
lte	47	15	0	27	10M	952	0	0%	27.8	29.5	31	20	310k	153	0	0%	0.0
lte	47	15	0	27	11M	1000	0	0%	27.4	29.6	29	21	463k	118	0	0%	0.0
lte	47	15	0	27	11M	999	0	0%	27.2	29.5	29	21	334k	94	0	0%	0.0

DL									UL								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	27	11M	1001	0	0%	27.3	29.2	29	21	301k	97	0	0%	0.0
lte	47	15	0	27	11M	1000	0	0%	27.3	29.4	29	21	324k	91	0	0%	0.0
lte	47	15	0	27	11M	999	0	0%	26.6	29.4	30	22	910k	184	0	0%	0.0
lte	47	14	0	27	11M	1001	0	0%	24.7	28.6	28	21	4.4M	841	0	0%	3.54k
lte	47	14	0	27	11M	1000	0	0%	27.3	29.0	28	22	5.4M	959	0	0%	47.3k
lte	47	15	0	27	11M	999	0	0%	24.7	n/a	30	23	5.6M	999	0	0%	126k
lte	47	15	0	27	11M	1001	0	0%	23.3	n/a	28	23	5.6M	1001	0	0%	145k
lte	47	15	0	26	8.8M	865	0	0%	24.1	n/a	28	23	5.6M	999	0	0%	145k
lte	47	15	0	27	11M	1001	0	0%	24.1	n/a	28	23	5.6M	1001	0	0%	148k
lte	47	15	0	27	11M	1000	0	0%	24.3	n/a	28	23	5.6M	1000	0	0%	145k

lte	47	15	0	27	11M	999	0	0%	24.4	n/a	30	23	5.6M	999	0	0%	148k
-----DL-----									-----UL-----								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	27	11M	1001	0	0%	24.1	n/a	30	23	5.6M	1001	0	0%	149k
lte	47	15	0	27	10M	989	0	0%	23.3	n/a	30	23	5.6M	1000	0	0%	147k
lte	47	15	0	27	9.7M	954	0	0%	23.7	n/a	31	23	5.6M	999	0	0%	148k
lte	47	15	0	27	11M	1001	0	0%	20.9	n/a	31	23	5.6M	1001	0	0%	146k
lte	47	15	0	27	11M	1000	0	0%	20.2	n/a	31	22	5.6M	999	1	0%	149k
lte	47	15	0	27	11M	999	0	0%	24.6	30.0	31	22	4.2M	768	0	0%	0.0
lte	47	15	0	27	11M	1001	0	0%	26.8	29.3	30	21	393k	103	0	0%	0.0
lte	47	15	0	27	8.6M	814	0	0%	27.4	29.6	32	20	373k	119	0	0%	0.0
lte	47	15	0	27	11M	988	0	0%	27.5	30.0	29	22	775k	169	0	0%	0.0
lte	47	15	0	27	11M	1001	0	0%	27.6	30.0	30	22	996k	207	0	0%	0.0
lte	47	15	0	27	11M	1000	0	0%	27.6	30.0	30	21	954k	201	0	0%	255
-----DL-----									-----UL-----								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	27	11M	1000	0	0%	27.5	30.0	30	22	1.1M	215	0	0%	0.0
lte	47	15	0	27	11M	1000	0	0%	27.7	30.1	30	22	975k	218	0	0%	0.0
lte	47	15	0	27	11M	999	0	0%	27.6	30.0	30	22	961k	206	0	0%	0.0
lte	47	15	0	27	11M	1001	0	0%	27.5	29.9	30	22	980k	200	0	0%	252
lte	47	15	0	27	11M	1000	0	0%	27.3	29.8	30	22	1.0M	211	0	0%	0.0
lte	47	15	0	27	11M	999	0	0%	27.4	30.2	30	22	1.1M	215	0	0%	0.0
lte	47	15	0	27	11M	1001	0	0%	27.4	30.1	30	22	964k	199	0	0%	252
lte	47	15	0	24	3.6M	413	0	0%	27.1	28.0	30	22	1.5M	291	0	0%	150k
lte	47	15	0	12	124k	264	0	0%	27.4	n/a	28	23	5.6M	999	0	0%	145k
lte	47	15	0	12	124k	263	0	0%	28.5	n/a	28	23	5.6M	1001	0	0%	147k
lte	47	14	0	12	137k	286	0	0%	25.6	n/a	28	23	5.6M	1000	0	0%	149k
-----DL-----									-----UL-----								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	12	142k	294	0	0%	25.9	n/a	29	23	5.6M	999	0	0%	149k
lte	47	14	0	13	154k	295	0	0%	28.5	n/a	27	23	5.6M	1001	0	0%	150k
lte	47	14	0	27	11M	997	0	0%	26.5	n/a	28	23	5.6M	1000	0	0%	147k
lte	47	14	0	27	11M	1000	0	0%	22.5	n/a	29	22	5.4M	1000	0	0%	145k
lte	47	14	0	27	11M	1000	0	0%	25.9	n/a	28	22	5.5M	1000	0	0%	145k
lte	47	14	0	25	6.6M	711	0	0%	24.6	n/a	30	23	5.5M	992	8	0%	146k
lte	47	15	0	17	241k	326	0	0%	15.4	n/a	33	19	4.3M	954	41	4%	149k
lte	47	15	0	15	235k	387	0	0%	18.9	n/a	33	21	5.2M	1000	0	0%	148k
lte	47	15	0	12	123k	263	0	0%	23.0	18.1	34	22	4.9M	879	0	0%	0.0
lte	47	15	0	11	3.3k	4	0	0%	23.1	3.9	35	22	8.3k	2	0	0%	0.0
lte	47	15	0	8	1.3k	3	0	0%	24.8	4.5	37	22	8.3k	2	0	0%	0.0
-----DL-----									-----UL-----								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	0	0	0	0	0%	n/a	2.8	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	2.9	0	0	0	0	0	0%	0.0
lte	47	14	0	0	0	0	0	0%	n/a	2.8	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	1.8	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	-0.2	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	1.4	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	1.9	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	0.4	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	1.4	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	2.2	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	0.7	0	0	0	0	0	0%	0.0
-----DL-----									-----UL-----								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	15	96k	29	0	0%	28.1	16.4	34	22	126k	29	0	0%	0.0
lte	47	15	0	19	501k	79	0	0%	18.7	17.1	34	20	152k	40	1	2%	0.0
lte	47	15	0	8	544	2	0	0%	25.2	5.0	34	21	11k	4	0	0%	0.0
lte	47	15	0	15	210k	64	0	0%	26.2	21.5	31	21	180k	41	0	0%	0.0
lte	47	15	0	13	70k	25	0	0%	25.4	12.5	34	21	70k	16	0	0%	0.0
lte	47	15	0	19	248k	42	0	0%	23.1	11.2	36	22	54k	13	0	0%	0.0
lte	47	15	0	18	153k	26	0	0%	22.9	8.9	35	22	41k	10	0	0%	0.0
lte	47	15	0	13	10k	4	0	0%	28.7	4.7	36	22	12k	3	0	0%	0.0
lte	47	15	0	0	832	2	0	0%	25.5	3.0	37	22	8.3k	2	0	0%	0.0
lte	47	15	0	12	13k	11	0	0%	29.6	10.2	32	21	39k	11	0	0%	0.0
lte	47	15	0	0	888	3	0	0%	28.2	4.2	30	22	12k	3	0	0%	0.0
-----DL-----									-----UL-----								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	14	0	0	832	2	0	0%	29.3	4.4	30	22	8.3k	2	0	0%	0.0
lte	47	15	0	0	832	2	0	0%	29.3	3.8	30	22	8.3k	2	0	0%	0.0
lte	47	15	0	0	832	2	0	0%	29.1	4.8	30	22	8.3k	2	0	0%	0.0
lte	47	15	0	7	832	2	0	0%	29.6	4.8	28	22	8.3k	2	0	0%	0.0
lte	47	15	0	0	832	2	0	0%	30.6	4.6	28	22	8.3k	2	0	0%	0.0
lte	47	15	0	25	1.3M	148	0	0%	30.1	25.8	29	22	108k	34	0	0%	0.0
lte	47	15	0	25	3.3M	350	0	0%	29.9	30.5	29	22	178k	43	0	0%	0.0
lte	47	14	0	26	5.6M	558	0	0%	29.3	31.4	29	22	207k	50	0	0%	0.0
lte	47	14	0	27	9.0M	855	0	0%	32.6	32.6	30	20	262k	116	0	0%	0.0
lte	47	14	0	27	11M	994	0	0%	32.9	33.4	29	20	285k	121	0	0%	0.0

lte	47	14	0	27	11M	1001	0	0%	32.5	33.4	28	20	285k	101	0	0%	0.0
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DL									UL								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	14	0	27	11M	1000	0	0%	32.8	33.5	28	21	297k	103	0	0%	0.0
lte	47	14	0	27	8.1M	774	0	0%	32.1	33.0	29	21	655k	161	0	0%	0.0
lte	47	14	0	13	133k	273	0	0%	31.9	32.5	26	22	5.4M	974	0	0%	39.1k
lte	47	14	0	12	129k	264	0	0%	31.9	n/a	25	23	5.6M	1000	0	0%	79.5k
lte	47	14	0	12	128k	262	0	0%	32.7	n/a	21	23	5.6M	998	2	0%	107k
lte	47	14	0	12	132k	267	0	0%	23.7	n/a	25	23	5.6M	1000	0	0%	146k
lte	47	14	0	12	83k	172	0	0%	23.1	12.5	26	22	3.4M	611	0	0%	0.0
lte	47	14	0	12	8.9k	5	0	0%	23.0	5.3	28	21	29k	7	0	0%	0.0
lte	47	14	0	0	0	0	0	0%	n/a	1.2	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	1.4	0	0	0	0	0	0%	0.0
lte	47	14	0	0	0	0	0	0%	n/a	2.1	0	0	0	0	0	0%	0.0

DL									UL								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	14	0	0	0	0	0	0%	n/a	2.1	0	0	0	0	0	0%	0.0
lte	47	14	0	0	0	0	0	0%	n/a	1.3	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	1.4	0	0	0	0	0	0%	0.0
lte	47	14	0	0	0	0	0	0%	n/a	2.1	0	0	0	0	0	0%	0.0
lte	47	14	0	11	21k	13	0	0%	18.4	7.6	30	21	39k	11	0	0%	0.0
lte	47	14	0	21	357k	50	0	0%	15.6	12.0	31	19	69k	16	1	5%	0.0
lte	47	15	0	15	86k	25	0	0%	24.6	12.0	35	21	62k	15	0	0%	0.0
lte	47	15	0	0	832	2	0	0%	24.8	3.0	33	22	8.3k	2	0	0%	0.0
lte	47	15	0	9	1.9k	5	0	0%	29.1	6.1	31	22	17k	4	0	0%	0.0
lte	47	15	0	9	11k	12	0	0%	28.1	9.4	32	21	39k	11	0	0%	0.0
lte	47	15	0	0	832	2	0	0%	27.1	4.0	32	22	8.3k	2	0	0%	0.0

DL									UL								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	0	832	2	0	0%	27.0	4.4	32	22	8.3k	2	0	0%	0.0
lte	47	15	0	0	832	2	0	0%	28.1	4.5	32	22	8.3k	2	0	0%	0.0
lte	47	15	0	0	832	2	0	0%	28.5	4.9	32	22	8.3k	2	0	0%	0.0
lte	47	15	0	0	832	2	0	0%	28.2	4.8	33	22	8.3k	2	0	0%	0.0
lte	47	15	0	7	1.4k	4	0	0%	29.3	5.8	32	22	12k	3	0	0%	0.0
lte	47	15	0	25	2.1M	236	0	0%	29.0	29.9	32	21	171k	43	0	0%	0.0
lte	47	15	0	26	3.8M	389	0	0%	29.6	30.6	31	22	165k	40	0	0%	0.0
lte	47	15	0	27	6.2M	605	0	0%	29.2	30.9	32	21	190k	53	0	0%	0.0
lte	47	15	0	27	8.8M	837	0	0%	30.2	31.6	32	20	241k	85	0	0%	247
lte	47	15	0	27	10M	965	0	0%	31.3	32.0	34	19	305k	150	0	0%	242
lte	47	15	0	27	11M	999	0	0%	30.2	31.4	34	19	302k	135	0	0%	176

DL									UL								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	27	11M	1001	0	0%	30.0	31.2	32	21	301k	111	0	0%	0.0
lte	47	15	0	27	11M	1000	0	0%	29.4	31.3	32	21	523k	130	0	0%	232
lte	47	15	0	24	4.5M	519	0	0%	28.8	31.0	31	22	2.7M	489	0	0%	29.9k
lte	47	15	0	12	129k	263	0	0%	28.5	n/a	31	23	5.6M	1000	0	0%	64.2k
lte	47	15	0	12	140k	270	0	0%	28.4	n/a	31	23	5.6M	1000	0	0%	109k
lte	47	15	0	13	167k	314	0	0%	28.4	n/a	31	23	5.6M	1000	0	0%	76.7k
lte	47	15	0	12	129k	261	0	0%	28.5	n/a	31	23	5.6M	1000	0	0%	92.1k
lte	47	15	0	11	27k	49	0	0%	28.6	14.2	32	22	674k	125	0	0%	0.0
lte	47	15	0	9	9.8k	5	0	0%	27.9	5.1	33	21	19k	5	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	1.6	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	1.6	0	0	0	0	0	0%	0.0

DL									UL								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	0	0	0	0	0%	n/a	1.7	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	1.8	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	1.7	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	2.0	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	1.1	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	0.8	0	0	0	0	0	0%	0.0
lte	47	15	0	10	13k	9	0	0%	12.8	2.7	36	17	19k	7	2	22%	0.0
lte	47	15	0	23	448k	56	0	0%	15.1	13.8	34	17	122k	35	6	14%	0.0
lte	47	14	0	16	281k	61	0	0%	24.9	18.9	32	21	130k	37	0	0%	0.0
lte	47	14	0	16	39k	14	0	0%	17.5	8.4	28	19	55k	14	2	12%	0.0
lte	47	15	0	7	832	2	0	0%	8.8	-0.5	33	14	6.2k	2	1	33%	0.0

DL									UL								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	8	2.5k	7	0	0%	13.2	1.7	35	16	18k	5	0	0%	0.0
lte	47	15	0	0	832	2	0	0%	11.2	0.5	35	16	7.5k	2	1	33%	0.0
lte	47	15	0	7	10k	10	0	0%	23.4	7.9	34	21	38k	11	0	0%	0.0
lte	47	15	0	0	832	2	0	0%	23.5	2.8	36	22	8.3k	2	0	0%	0.0
lte	47	15	0	0	832	2	0	0%	23.3	2.7	36	22	8.3k	2	0	0%	0.0
lte	47	15	0	10	10k	8	0	0%	14.4	3.6	36	18	37k	10	1	9%	0.0
lte	47	15	0	5	888	3	0	0%	14.3	1.7	36	20	13k	3	0	0%	0.0
lte	47	15	0	24	1.4M	160	0	0%	16.1	12.9	36	19	115k	37	0	0%	0.0
lte	47	15	0	26	3.6M	371	0	0%	19.1	17.0	37	21	244k	89	0	0%	0.0

lte	47	15	0	26	4.9M	488	0	0%	18.5	18.6	37	22	153k	37	0	0%	0.0
lte	47	15	0	27	6.3M	617	0	0%	17.6	17.9	37	22	207k	50	0	0%	0.0
-----DL-----									-----UL-----								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	27	7.7M	740	0	0%	17.9	18.8	37	22	207k	50	0	0%	0.0
lte	47	15	0	27	8.5M	808	0	0%	18.8	19.1	37	21	234k	72	0	0%	0.0
lte	47	15	0	27	10M	965	0	0%	19.3	19.2	38	19	286k	132	0	0%	0.0
lte	47	15	0	27	11M	1000	0	0%	19.2	19.5	37	21	293k	89	0	0%	248
lte	47	15	0	27	11M	1000	0	0%	19.1	19.1	37	21	285k	108	0	0%	0.0
lte	47	15	0	27	11M	1000	0	0%	18.4	18.5	37	20	471k	138	0	0%	0.0
lte	47	15	0	27	11M	1000	0	0%	18.6	18.5	38	19	314k	152	0	0%	255
lte	47	15	0	20	2.4M	408	0	0%	18.6	18.4	36	22	3.8M	694	0	0%	27.3k
lte	47	15	0	12	127k	260	0	0%	17.7	n/a	35	22	5.4M	1000	0	0%	63.6k
lte	47	15	0	12	125k	258	0	0%	17.8	n/a	36	22	5.4M	1000	0	0%	91.8k
lte	47	15	0	13	157k	295	0	0%	17.4	n/a	36	22	5.3M	1000	0	0%	77.4k
-----DL-----									-----UL-----								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	12	122k	237	0	0%	16.5	n/a	35	20	4.8M	1000	0	0%	109k
lte	47	15	0	12	42k	91	0	0%	16.0	3.4	35	20	1.7M	369	0	0%	0.0
lte	47	15	0	12	9.1k	4	0	0%	13.4	1.2	35	18	28k	7	1	12%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	-0.8	0	0	0	0	0	0%	0.0
lte	47	15	0	8	9.2k	7	0	0%	16.8	2.5	37	20	26k	8	0	0%	0.0
lte	47	15	0	0	56	1	0	0%	14.0	-0.5	37	22	4.1k	1	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	-2.1	0	0	0	0	0	0%	0.0
lte	47	14	0	0	0	0	0	0%	n/a	-1.0	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	1.2	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	1.9	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	1.5	0	0	0	0	0	0%	0.0
-----DL-----									-----UL-----								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	15	0	0	0	0	0	0%	n/a	2.3	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	2.0	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	1.7	0	0	0	0	0	0%	0.0
lte	47	15	0	0	0	0	0	0%	n/a	2.2	0	0	0	0	0	0%	0.0
lte	47	14	0	0	0	0	0	0%	n/a	2.4	0	0	0	0	0	0%	0.0
lte	47	14	0	0	0	0	0	0%	n/a	2.2	0	0	0	0	0	0%	0.0
lte	47	14	0	0	0	0	0	0%	n/a	-1.3	0	0	0	0	0	0%	0.0
lte	47	14	0	0	0	0	0	0%	n/a	1.1	0	0	0	0	0	0%	0.0
lte	47	14	0	0	0	0	0	0%	n/a	1.2	0	0	0	0	0	0%	0.0
lte	47	14	0	0	0	0	0	0%	n/a	2.1	0	0	0	0	0	0%	0.0
lte	47	14	0	0	0	0	0	0%	n/a	2.5	0	0	0	0	0	0%	0.0
-----DL-----									-----UL-----								
rat	rnti	cqi	ri	mcs	brate	ok	nok	(%)	pusch	pucch	phr	mcs	brate	ok	nok	(%)	bsr
lte	47	14	0	0	0	0	0	0%	n/a	2.5	0	0	0	0	0	0%	0.0
lte	47	14	0	0	0	0	0	0%	n/a	3.2	0	0	0	0	0	0%	0.0
lte	47	15	0	0	56	1	0	0%	15.0	0.4	38	18	4.4k	1	0	0%	0.0
lte	47	15	0	0	56	1	0	0%	26.9	3.0	36	18	4.4k	1	0	0%	0.0
lte	47	14	0	0	56	1	0	0%	29.4	2.8	26	22	4.1k	1	0	0%	0.0
lte	47	14	0	0	56	1	0	0%	26.9	2.8	30	22	4.1k	1	0	0%	0.0
qlte	47	15	0	0	0	0	0	0%	n/a	1.9	0	0	0	0	0	0%	0.0

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Glossary

IoT	Internet of Things
OFDM	Orthogonal Frequency Division Multiplexing
NSA	Non-standalone
NR	New Radio
LTE	Long Term Evolution
SA	Standalone
UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Access Network
E-UTRAN	Evolved UTRAN
eNB	Evolved NodeB
UE	User Equipment
CN	Core Network
IMS	IP Multimedia Subsystem
EPC	Evolved Packet Core
IP	Internet Protocol
MME	Mobility Management Entity
QoS	Quality of Service
NAS	Non-Access Protocol
S-GW	Serving Gateway
P-GW	Packet Data Gateway
HSS	Home Subscriber Server
ICIC	InterCell Interference Coordination
ME	Mobile Equipment
UICC	Universal Integrated Circuit Card
MSISDN	Mobile Station International Subscriber Directory Number
MNC	Mobile Network Code
MCC	Mobile Country Code
CC	Country Code
S1AP	S1 Application Protocol

SCTP	Stream Control Transmission Protocol
UDP	User Datagram Protocol
RRC	Radio Resource Control
PDCP	Packet Data Convergence Protocol
RLC	Radio Link Control
MAC	Medium Access Control
PHY	Physical
OFDMA	Orthogonal Frequency Division Multiple Access
SC-FDMA	Single-carrier Frequency Division Multiple Access
QPSK	Quadrature Phase Shift Keying
QAM	Quadrature Amplitude Modulation
PRB	Physical Resource Block
MIMO	Multiple Input Multiple Output
CDD	Cyclic Delay Diversity
USRP	Universal Software Radio Peripheral
UHD	USRP Hardware Driver
SDR	Software Defined Radio
IMSI	International Mobile Subscriber Identity
DL	Downlink
UL	Uplink
CPU	Central Processing Unit