Measurement and Optimization of LTE Performance

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XXX Cycle - III year presentation

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Background

Master Science Degree in “Ingegneria delle Telecomunicazioni” at University of Naples Federico II

Master "SIRIO-FORM Servizi per l'Infrastruttura di
Rete wIreless Oltre il 3g"

DIETI Group Comics Research Unit

Template

- CONTENT
  - Cover
  - Your background
    - Graduation MS, DIETI group, cooperations (mostly written)
    - Type of fellowship
  - Your problem
    - Specific (1 minutes)
  - Your research activity (3 minutes)
    - idea, methodology, developments, expected results, validation
  - Your products
    - List and mention
  - Next years
    - I year credits (table, mark in red if discrepancies occurs with PhD web site table)
    - Specific objects(say)
    - Table for training (expected credits) no words

Publication Report

- ***"A Load Balancing Algorithm against DDoS attacks in beyond 3G wireless networks"*** - Stefania Zinno, Giovanni Di Stasi, Stefano Avallone, Giorgio Ventre published in Euro Med Telco Conference (EMTC), 2014
- ***"On a Fair Coexistence of LTE and Wi-Fi in the Unlicensed Spectrum: A Survey*** " - Stefania Zinno, Giovanni Di Stasi, Stefano Avallone, Giorgio Ventre accettato in Computer Communications - Journal - Elsevier , (2017)
- ***"Smartphone-based Measurements of LTE Network Performance"*** - Stefano Avallone, Nicola Pasquino, Stefania Zinno and Domenico Casillo pubblicato in International Instrumentation Measurement Conference (IMTC) , 2017
- ***"Experimental characterization of LTE Adaptive Modulation and Coding scheme under actual operating conditions"*** - Stefano Avallone, Nicola Pasquino, Stefania Zinno and Domenico Casillo in 2017 IEEE International Workshop on Measurements and Networking (M&N)
- ***"VERIFICA SPERIMENTALE DELLE PRESTAZIONI DELLA RETE LTE MEDIANTE MISURE BASATE SU SMARTPHONE*"** - Stefano Avallone, Nicola Pasquino, Stefania Zinno and Domenico Casillo sottomesso in GMEE, I Forum Nazionale delle Misure XXXIV Congresso Nazionale di Misure Elettriche ed Elettroniche XXV Congresso nazionale di Misure Meccaniche e Termiche, (2017)
- ***"Radio Optimisation and Measurement Procedure in LTE"*** **Stefania Zinno** - MOBILE SYSTEM TECHNOLOGIES (MST2017) October 27 2017
- ***"La verifica sperimentale delle prestazioni del sistema LTE, Il cellulare come strumento di misura"*** accettato per la pubblicazione su TUTTO MISURE - Rivista Nazionale (2017)

Outline

- *LTE Basics Overview*
- *Smartphone Based Campaign*
- *Measurement Assessment with Nemo Analyser*
- *LTE in the Unlicensed Bandwidth*

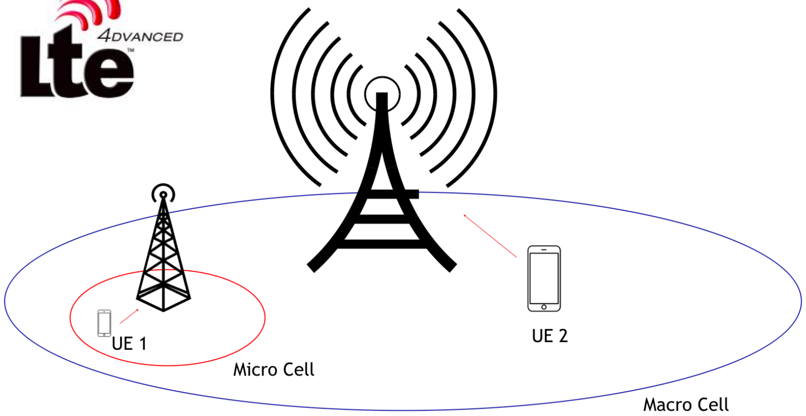
Long Term Evolution 4G

The downlink channel of the LTE mobile communication system makes use of Orthogonal Frequency Division Multiple Access (OFDMA)

All subcarriers accessed by multiple users at the same time. During each time slot, each user can be allocated a set of such subcarriers, named Resource Blocks (RB), to enable concurrent transmission.

LTE also adopts Carrier Aggregation adopting more than one carrier for a single user to increase the overall transmission bandwidth.

Scheduling process takes place in the eNodeB



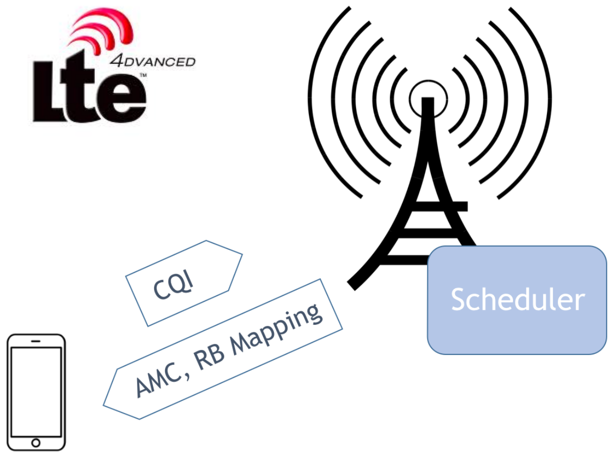
Adaptive Modulation and Coding

eNodeB adopts a link adaption procedure (AMC) to increase spectral efficiency of shared channel adapting modulation scheme and code rate to channel conditions.

Using a feedback mechanism, the User Equipment (UE) periodically reports to the eNodeB the measured channel quality trough the CQI.

The standard does not mandate how UEs compute the CQI but values are based on reported SINR values. Each CQI value is associated with a MCS index and a spectral effiency (b/s/Hz) and coding rate.

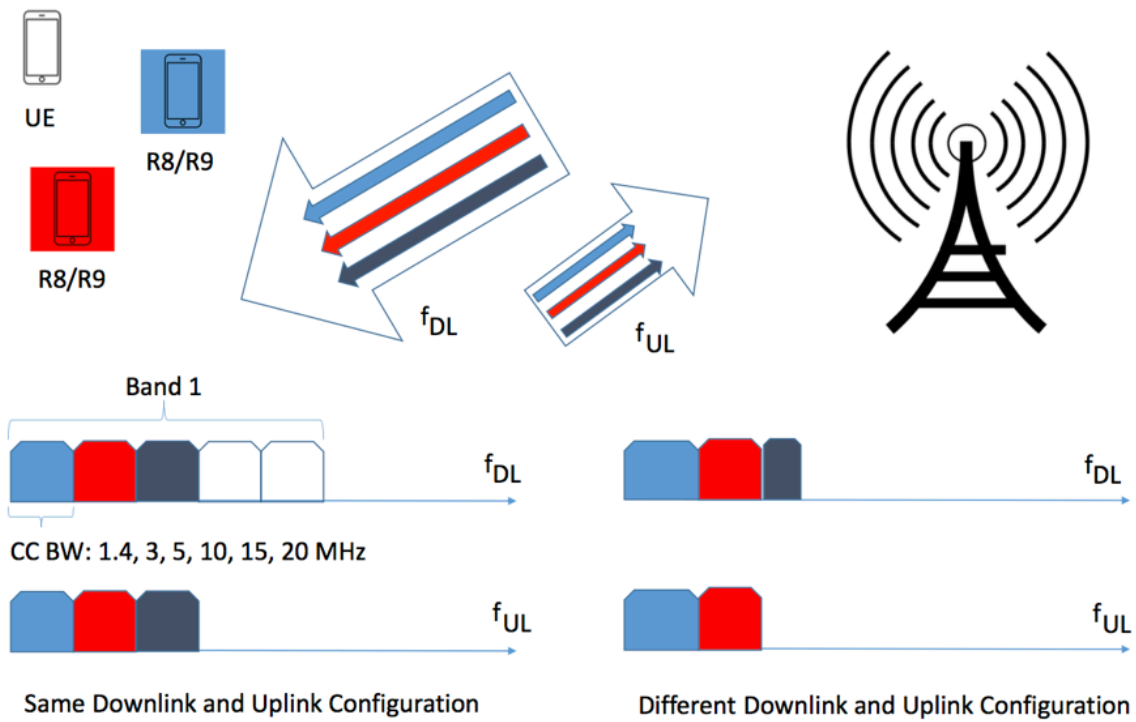
With high values of on CQI, higher order modulation schemes with higher spectral efficiency (hence with higher bit rates) like 64QAM are used.



Carrier Aggregation Mechanism in LTE

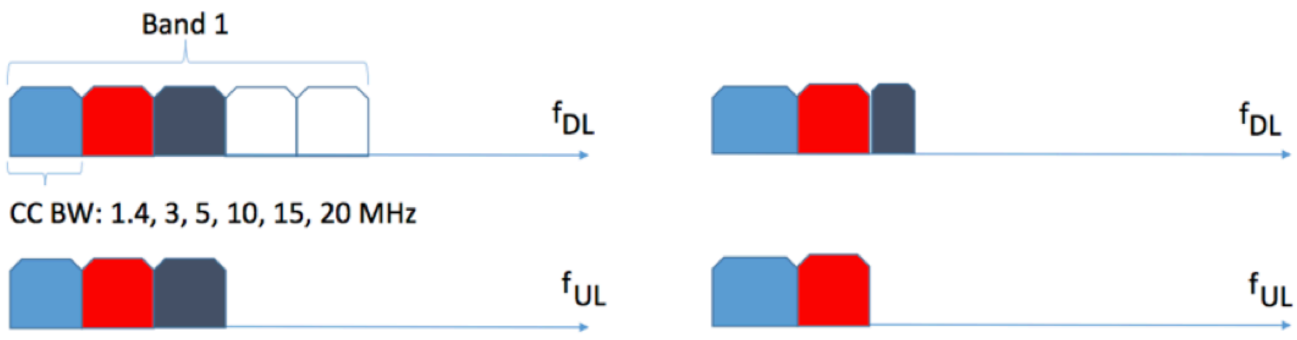
Carrier aggregation allows the use of extra channels to achieve higher capacity. Each station is always connected to:

- **Primary Component Carrier (PCC)**.
- **Secondary Component Carriers (SCC)**,



Predicted Throughput

Different bandwidth are presented: 1.4, 3, 5, 10, 15, 20 MHz and play a key role in affecting throughput value. Each bandwidth is composed by a specific number of Resource Blocks (RBs)



MAC layer selects the modulation and coding scheme to configure the physical layer transmissions and wrap everything into a Transport Block Size (TBS). The quantity of bits transferred in a 1ms transport block size strictly depends on the MCS and the number of resource blocks assigned to each UE.

If the eNodeB selects a MCS 20 and assigns 2 RBs based on the received CQI, it is evident that TBS index is equal to 18. Referring to the standard Table 7.1.7.2.1-1 of [14], to a index 18 with 2 RB corresponds a TB of 776 bit. We will have a single TB in a TTI (1ms):

$$T_{nom} = 776 bits \cdot 1000 = 776000 bits/second = 0.77 Mbps$$

Smartphone Based Campaign

Drive Test Campaign

Conducted over *a 9.75 km extra-city route* in the area of Naples, Italy.

The measurement device was put in a vehicle moving with an average *speed of 49 km/h*

Measurement result is geo- and time-referenced through the embedded GPS device

A *high-bandwidth stress test* with continuous download of a large files (200 Mb) from a remote server using the HTTP protocol

Handover between different technologies is *prevented* by forcing the device to connect to LTE network only

Measurement Session Route

Smartphone Based Campaign

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- The measurement device was put in a vehicle moving with an average *speed of 49 km/h*
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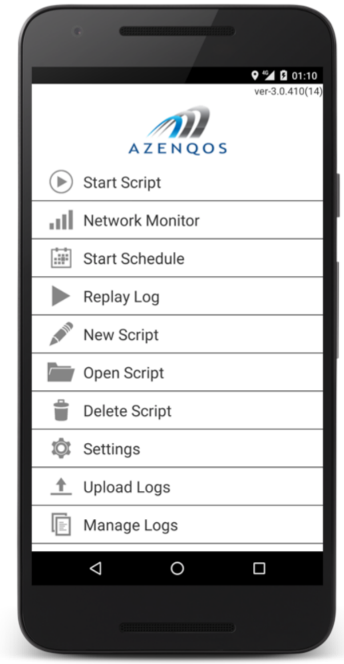
- *Handover* between different technologies is *prevented* by forcing the device to connect to LTE network only



AZQ Android Tool

AZQ Android Driving Test Tool Suite

The suite can be used in two different ways: a *network monitor* that collects information in a passive way, or users can define their own *script* to run and track multiple network parameters.

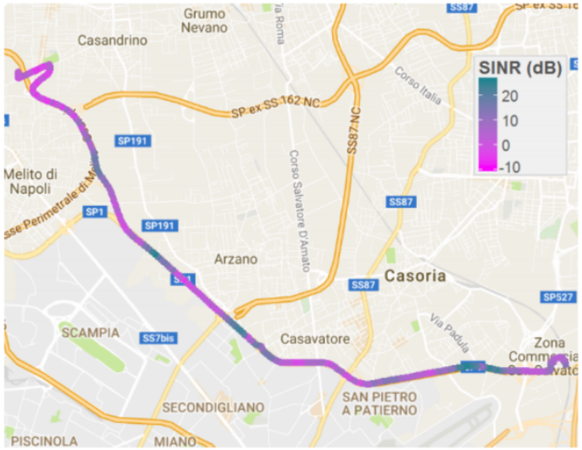
Several interesting features are available:

- *Baseband Locking* force the use of one particular technology
- *LTE PCI/EARFCN Lock* connect to a particular eNodeB;
- *LTE Band Lock* force the use of certain frequency ranges;
- *LTE Radio* display radio interface parameters in real-time;
- *LTE Cells* display the list of the eNodeBs and RSRP and RSRQ;
- *LTE Data* display throughput, MIMO scheme, RB, MCS and TBS.

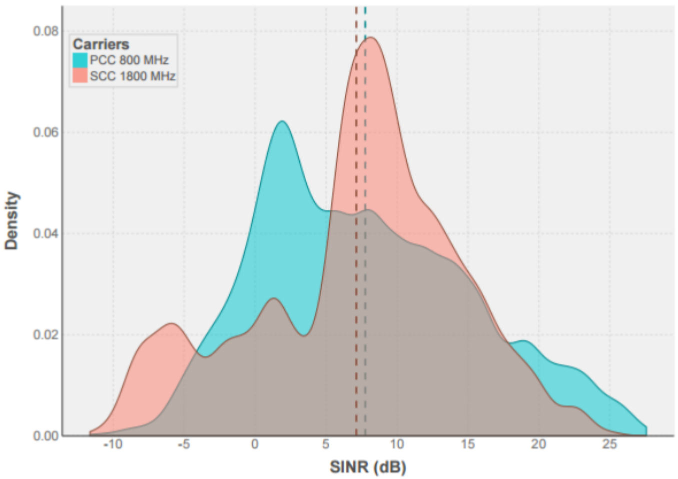
Device	Version
LG Nexus 5X	Android 6.0 MBD08M
BaseBands	Qualcomm M8994F 2.6.28.0.65
Kernel	3.10.73-azq_kernel
AZQ Android Tool	3.0.410(14)

Measurement Device and Software Versions

SINR



SINR Evolution

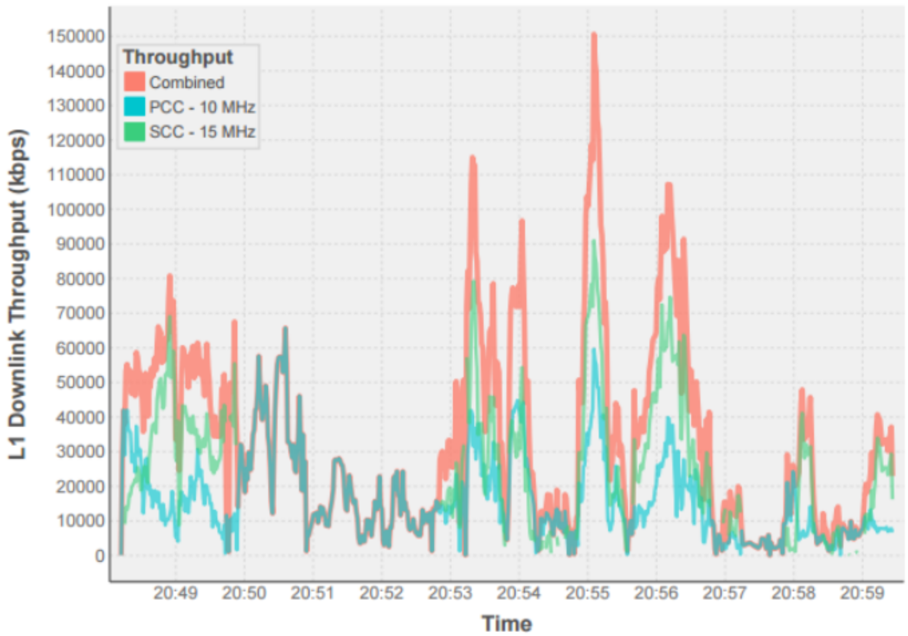


SINR Empirical Distribution

We can observe a non-homogeneous distribution of values, spanning over 40dB

Min	-11.06	-11.64
Average	7.76	7.13
Max	27.58	25.30
Median	7.55	7.30

Throughput



Downlink Throughput over time

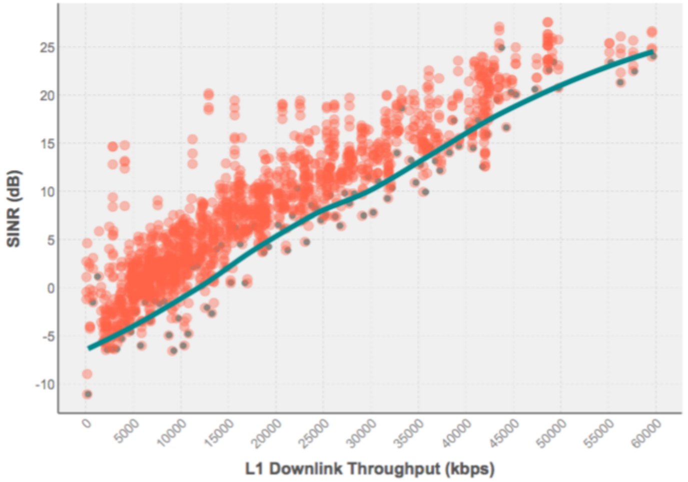
Downlink throughput is measured at the physical layer (L1)

A few points on the route achieve high values close to the theoretical limit of 150 Mbps.

A high variability of measured values is immediately noticeable. Peaks are high and well distinguishable and we observe a strong increase in throughput when the Carrier Aggregation mechanism is in use.

SINR VS Throughput

Throughput Mbps	Min	Avg	Max
10	-6.53	1.57	9.10
20	0.50	8.25	19.42
30	6.45	12.84	19.72
40	9.93	16.26	23.53
50	20.05	24.11	27.58
60	21.32	24.41	26.65



SINR vs Throughput for PCC

CQI feedback and MCS

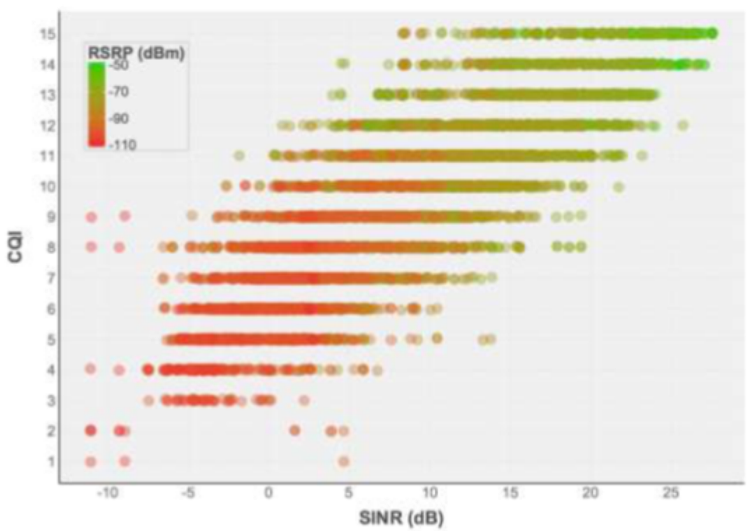
LTE standard defines the mutual correspondence between CQI and the encoding scheme as shown in Table I.The reported CQI is a number between 0 (worst case) and 15 (best case) indicating the most efficient MCS which would lead to a BLER of 10%.

Many factors play important roles to CQI measurement:

- *Signal-to-Interference Plus Noise Ratio (SINR)*
- *Reference Signal Received Power (RSRP)*
- *Received Signal Strength Indicator (RSSI)*
- *Reference Signal Received Quality (RSRQ)*

CQI	MODULATION	MCS
0	0	0
1	QPSK	1
2	QPSK	3
3	QPSK	5
4	QPSK	7
5	QPSK	9
6	QPSK	11
7	16QAM	13
8	16QAM	15
9	16QAM	17
10	64QAM	19
11	64QAM	21
12	64QAM	23
13	64QAM	25
14	64QAM	27
15	64QAM	29

SINR



CQI vs SINR

SINR plays a major role into link adaption procedure. But SINR itself does not represent a comprehensive channel state representation

It is very interesting to characterize which combination of SINR and RSRP values lead to a specific CQI value. In figure, CQI evolution is shown based on RSRP and SINR. RSRP values are represented by the different colors in each point in the plane. Generally, a first investigation let us conclude that a certain CQI value leads to a wide range of SINR and RSRP values.

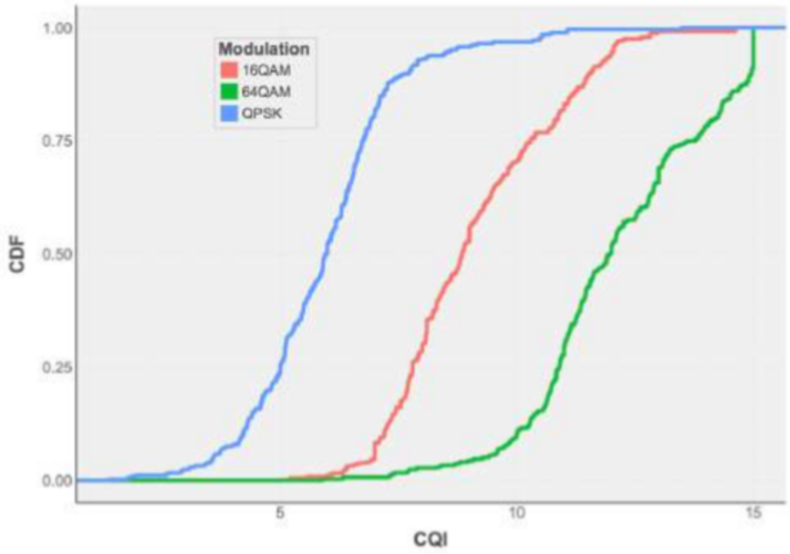
Also, it is quite noticeable that a high SINR values correspond high RSRP values.

CQI VS Modulation

CQI role is fundamental for Adaptive Modulation and Coding Mechanism. The choice of which modulation to use in fact, is up to the CQI value

CQI	QPSK	16QAM	64QAM
Min	1	5	6
Average	5.97	9.11	12.14
Max	13	15	15
Median	6	9	12
s	1.61	1.75	1.89
3GPP Sp.	1-6	7-9	10-15

CQI STATISTIC PER MODULATION

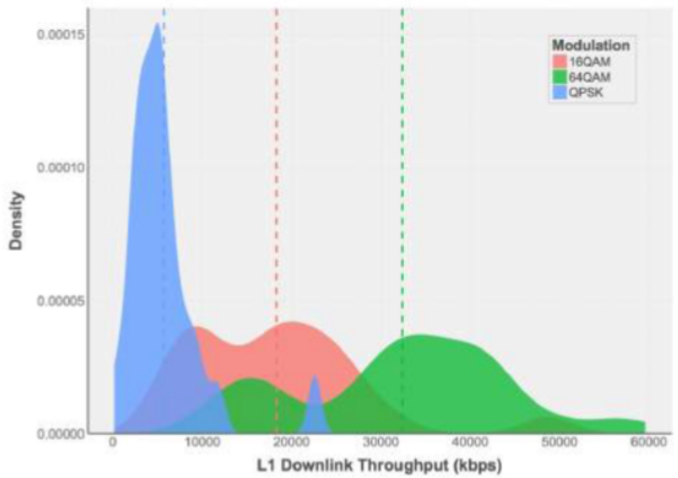


CQI CDF per Modulation

SINR and Modulation vs Throughput

Throughput Mbps	QPSK	16QAM	64QAM
Min	0.15	5.58	10.34
Average	5.70	18.27	32.36
Max	22.56	48.63	59.57
Median	4.86	18.44	33.23
s	4.33	9.73	11.89
Predicted	15.98	30.52	73.39

Throughput Statistics Per Modulation



SINR vs Throughput

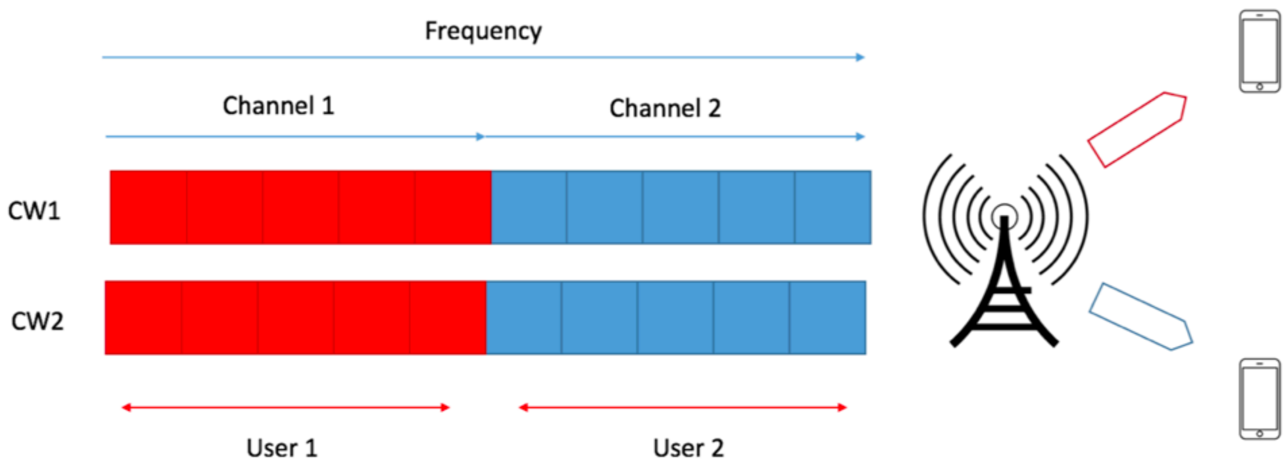
Measurement Assessment with Nemo Analyser

Single User MIMO Technique

Transmit multiple code-word to a single user in the same time-frequency interval.

Different modes are available:

- Transmit Diversity
- Spatial Multiplexing Mode
    - A Closed Loop Rank 1
    - B Open Loop
    - C Closed Loop



SU-MIMO

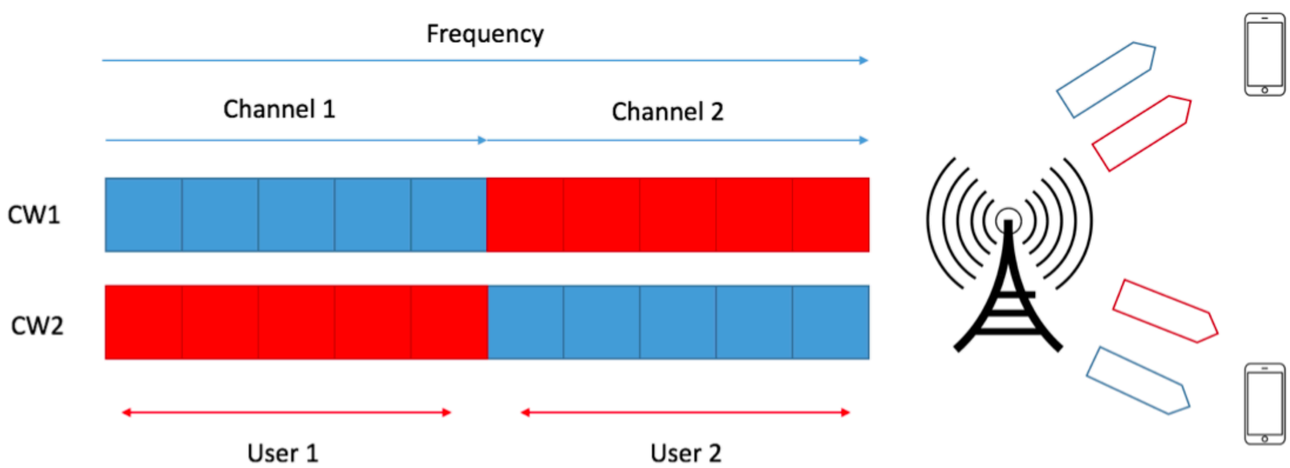
Multiple User MIMO Technique

In MU-MIMO, separate data streams are sent to spatially separated UEs over the same sub-channel.

Each UE serving has multiple Rx antennas. With this technique the overall system capacity is increased, though it does not increase throughput for individual UEs.

To achieve MU-MIMO better performances rich scattering conditions are necessary for each UE in order to decode the data stream meant for that particular UE.

LTE employs a precoded spatial multiplexing scheme with codebook feedback from users.



MU-MIMO

Nemo Analyzer

Cell measurement (CELLMEAS)

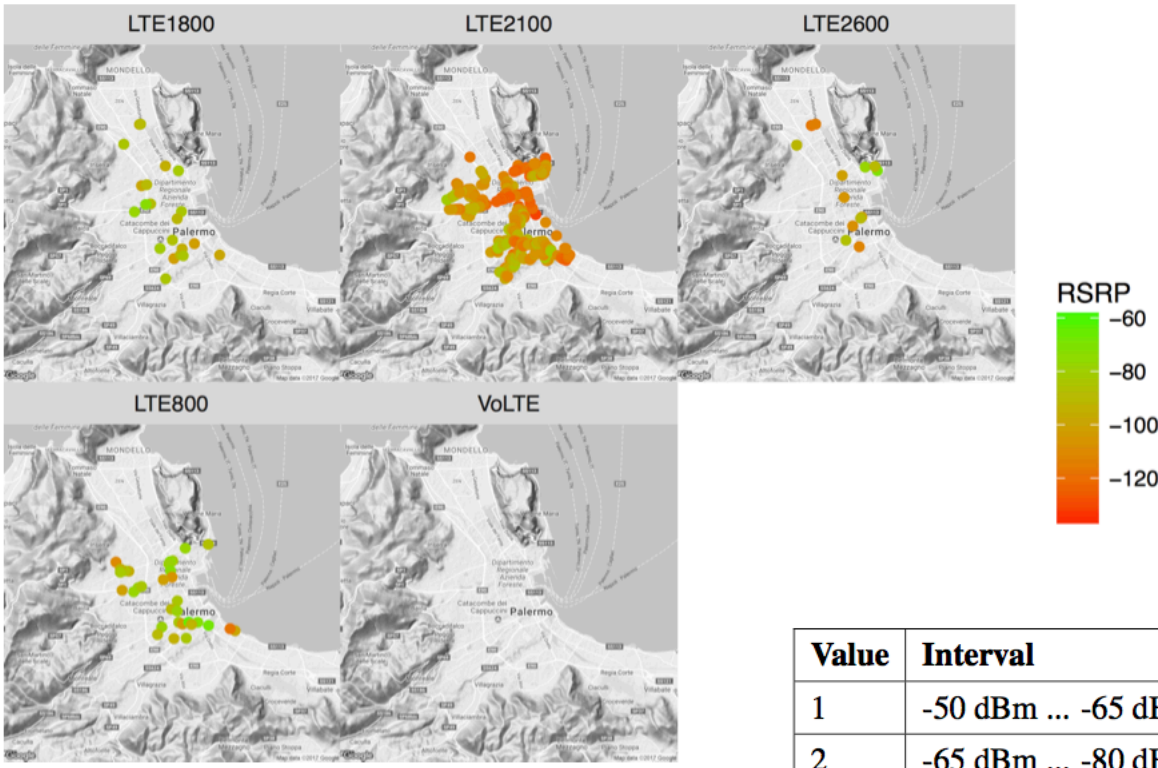
Event ID	CELLMEAS
Cellular systems	GSM,TETRA,UMTS FDD,UMTS TD-SCDMA,LTE FDD,LTE TDD,cdmaOne,CDMA 1x,EVDO,WLAN,GAN WLAN,WiMAX,AMPS,DAMPS,NAMPS,iDEN
Record state	Always
Description	Recorded when parameter sample is received from the device. Note that not necessarily all received samples are recorded and currently the recording frequency is about twice per second in connected state. Separate measurement event is logged for each system.
Tools	Nemo Outdoor, Nemo Handy, Nemo Autonomous, Nemo Q

|Parameters |Parameters for GSM |Parameters for TETRA |Parameters for UMTS FDD |Parameters for UMTS TD-SCDMA |Parameters for LTE |Parameters for cdmaOne and CDMA 1x |Parameters for EVDO |Parameters for WLAN |Parameters for GAN WLAN |Parameters for WiMAX |Parameters for AMPS and NAMPS |Parameters for DAMPS |Parameters for iDEN |

Nemo Analyzer was installed at the radio interface of an eNodeB. Nemo is an event based measurement suite that collects data for each event occurring. The following information is given for each event:

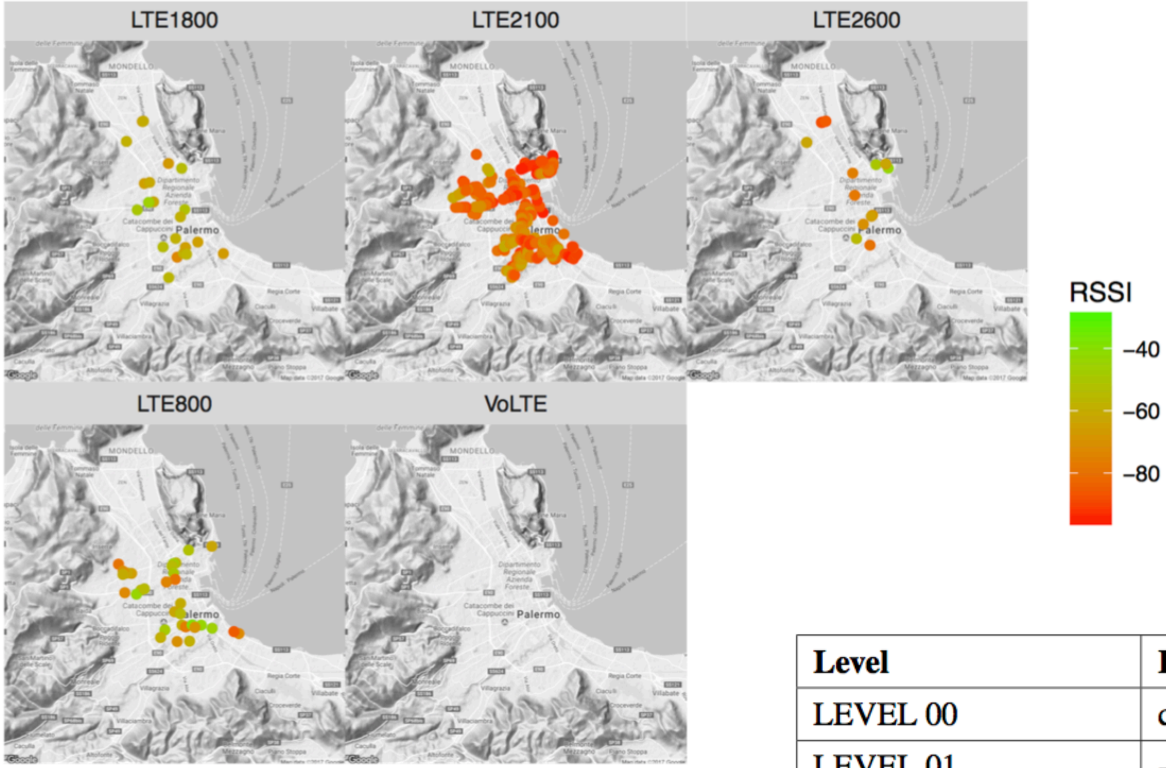
- **Event ID**
- **Cellular systems:**
- **Recorded**

RSRP



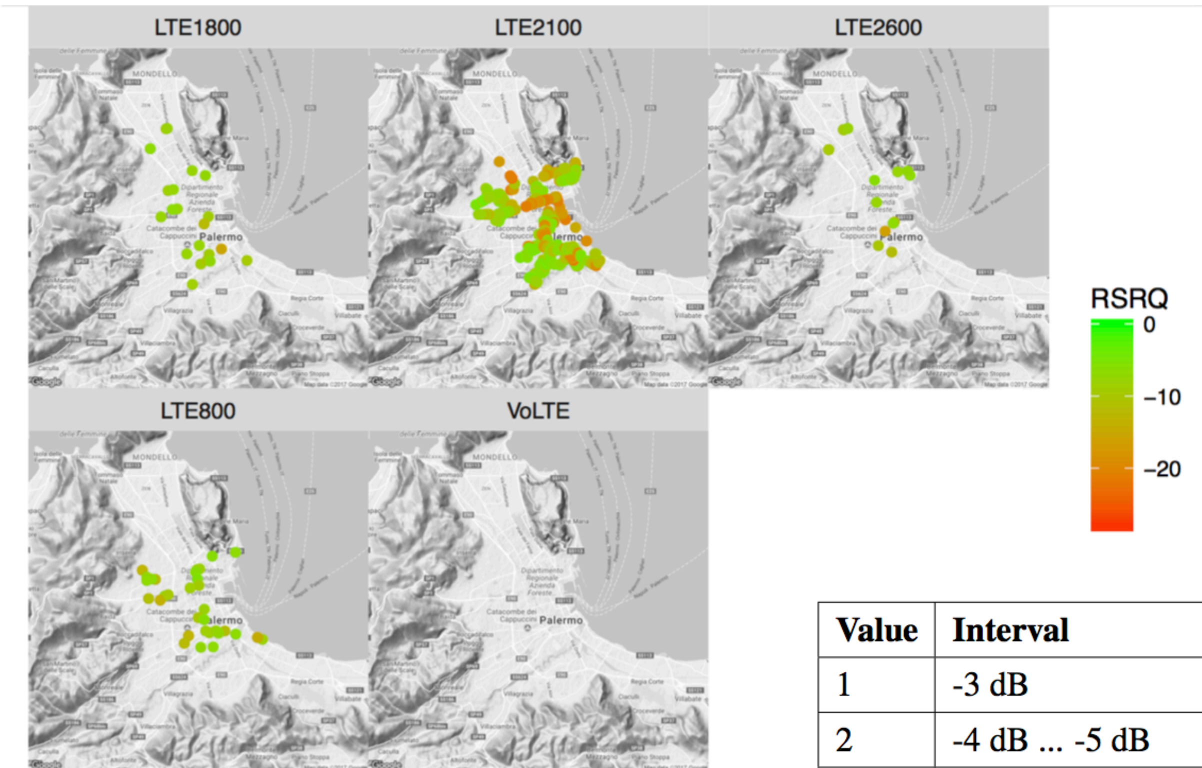
Value	Interval	Mapping
1	-50 dBm ... -65 dBm	very good
2	-65 dBm ... -80 dBm	good
3	-80 dBm ... -95 dBm	satisfying
4	-95 dBm ... -105 dBm	sufficient
5	-110 dBm ... -125 dBm	unsatisfying
6	-125 dBm ... -140 dBm	not sufficient

RSSI



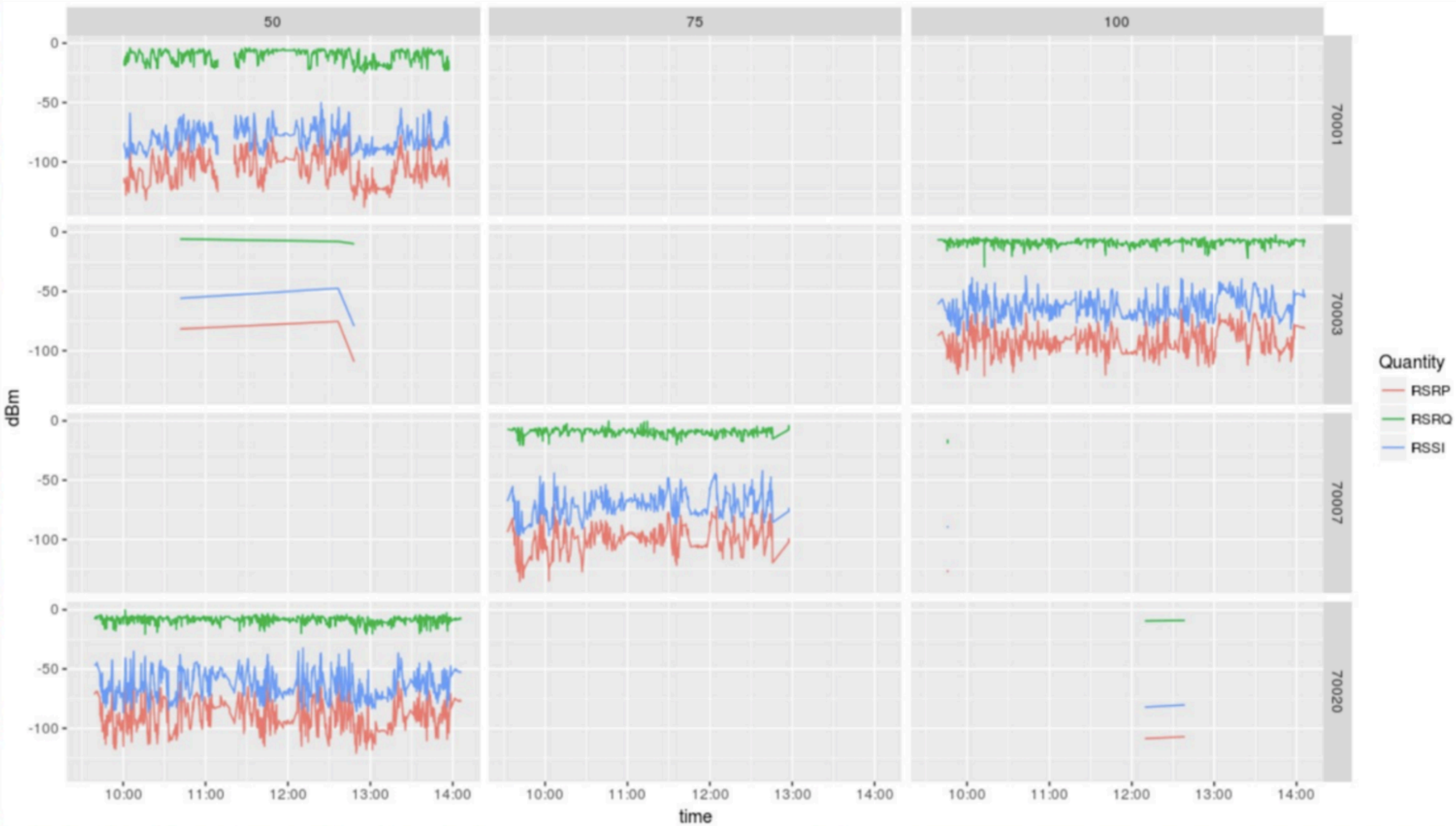
Level	Interval
LEVEL 00	carrier $\leq$ -100dBm
LEVEL 01	-100 dBm $\leq$ carrier $\geq$ -99 dBm
LEVEL 02	-99 dBm $\leq$ carrier $\geq$ -98 dBm
LEVEL ..	..
LEVEL 75	-26 dBm $\leq$ carrier $\geq$ -25 dBm
LEVEL 76	-25 dBm $\leq$ carrier

RSRQ

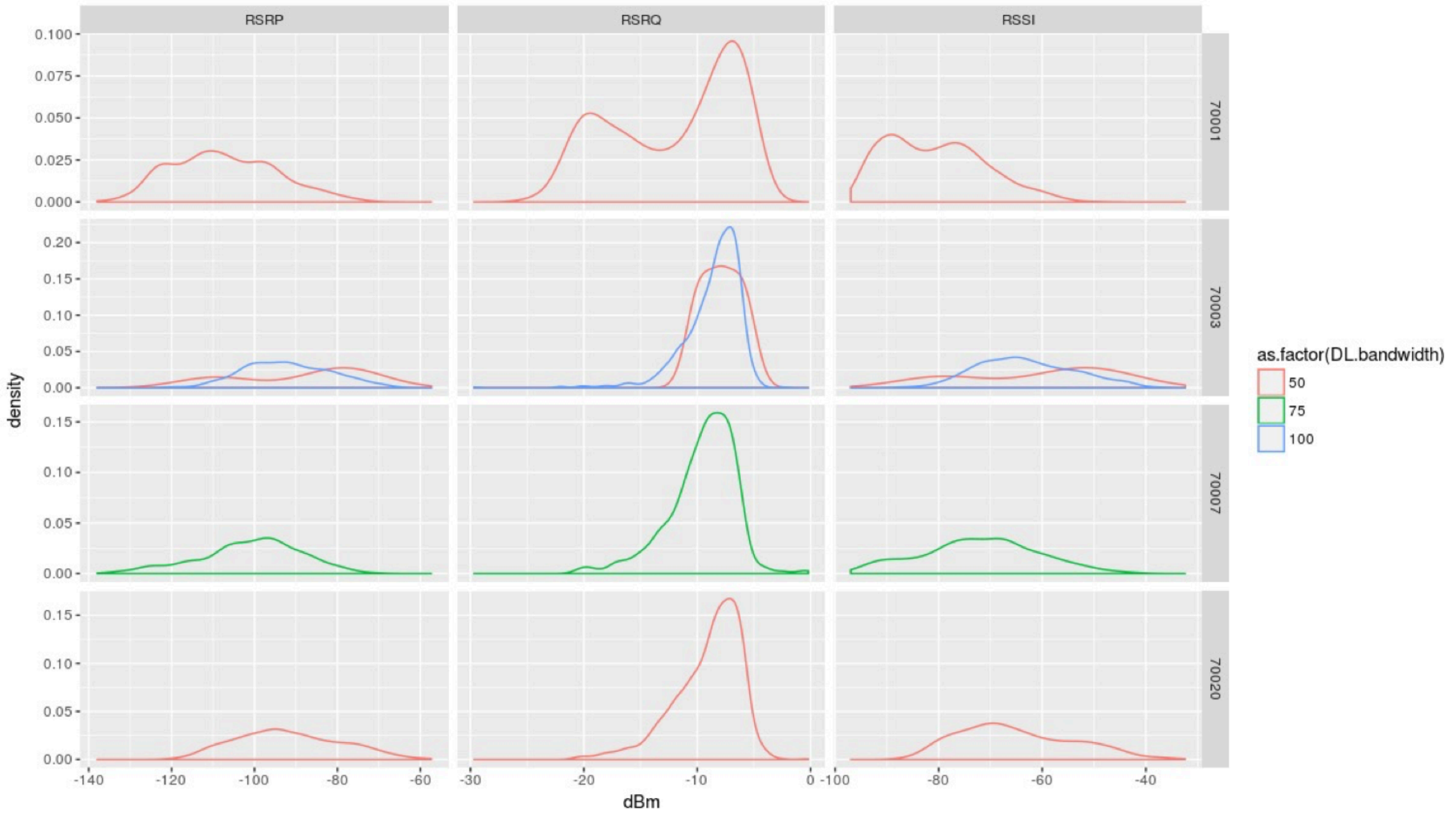


Value	Interval	Mapping
1	-3 dB	very good
2	-4 dB ... -5 dB	good
3	-6 dB ... -8 dB	satisfying
4	-9 dB ... -11 dB	sufficient
5	-12 dB ... -15 dB	unsatisfying
6	-16 dB ... -20 dB	insufficient

RSRP, RSRP, RSSI value per band



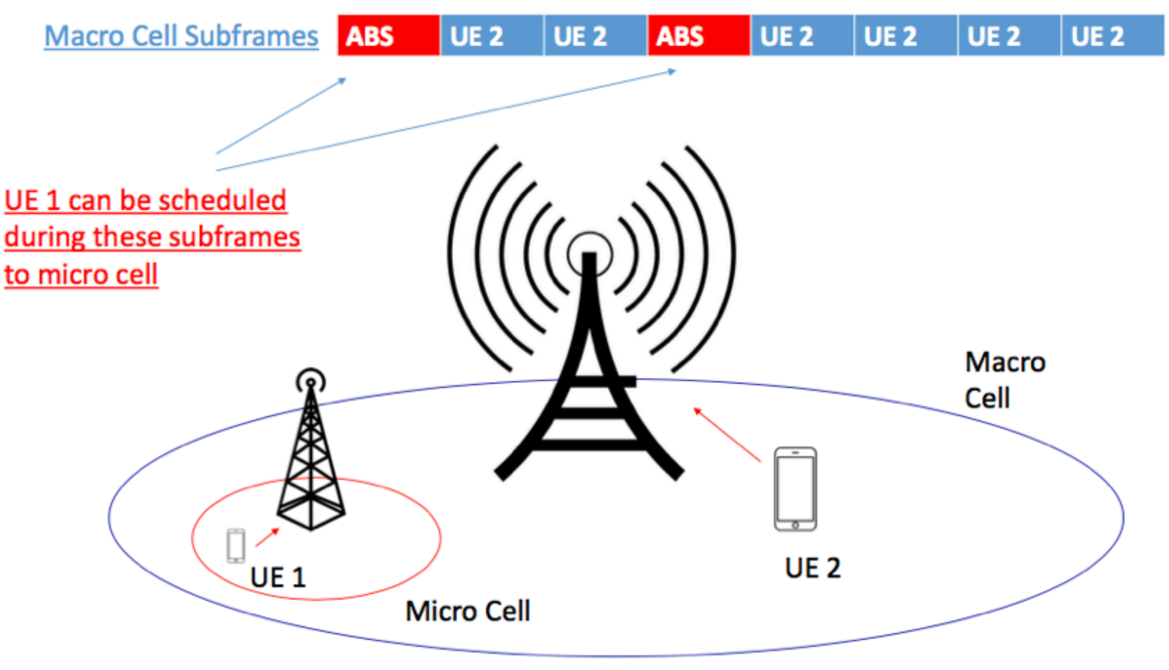
RSRP, RSRP, RSSI PDF



LTE in the Unlicensed Bandwidth

Fair Mechanism Coexistence

- **Listen-Before-Talk (LBT)** is a mechanism that consists in the assessment of the channel state before transmitting.
- **Category 1:** No LBT.
- **Category 2:** LBT without a random back-off procedure (deterministic)
- **Category 3:** LBT with random back-off having a fixed contention window (CW).
- **Category 4:** LBT with random back-off having a contention window of variable size.



Almost Blank Subframe

Survey

Table 3: Taxonomy of research works

Paper	CAT	Threshold	CW	Scenario	Model	PTX	Note
[38]	CAT 4	CCA-ED: -62dBM CCA-PD: -82dBM	CW_min 16, CW_max 1024	Indoor	FTP 2	18 dBm	CAT 4 Comparison
[39]	CAT 3		Fixed	LAA-LAA LAA-Wi-Fi			MARKOV
[40]	CAT 1			Indoor Single and Multi-Floor	Full buffer	23 dBm	
[41]	CAT 3	CCA-ED:-82 dBm Indoor -62 dBm Outdoor	Fixed CW and freeze period of 11 OFDM Symbol	2 x Wi-Fi vs Wi-Fi-LTE DL LAA vs DL Wi-Fi (DL+UL) Wi-Fi vs DL LAA	FTP 0.5 Mbyte - Non full buffer		
[42]	CAT 1	CCA-ED: -70 dBm	Fixed 18 micro sec	Office Indoor 3GPP Scenario		15 dBm	Channel Selection with Q-LEARNING
[22]	CAT 2?	CCA-ED: 62 dBm		Indoor LTE-U femtocell, outdoor LTE-U picocell vs Wi-Fi indoor		23 dBm	Channel Selection with MATLAB
[37]	CAT 3	CCA-ED: (-52,-62,-72,-82,-92)dBm	Fixed (32,128)	Outdoor/Mixed standalone plain coexistence	FTP 1 0.5 Mbyte	enodeB 30 dBm AP 20 dBm STA 17 dBm	
[32]	CAT 2	CCA-ED: Adaptive in [-82 dBm, -58 dBm]		Indoor Office	Full Buffer Data	24 dBm BS-AP 23 dBm Ue-STA	
[43]	CAT 3	CCA-ED: -82dBm	Fixed (32,128)	Outdoor - Mixed indoor outdoor - standalone plain coexistence	FTP 1	enodeB 30 dBm AP 20 dBm STA 17 dBm	No licensed band simulated RTS CTS self CTS
[44]	CAT 1			indoor scenario			Channel selection with Q-LEARNING
[45]	CAT 3	CCA-ED: Adaptive in [-30 dBm,-80 dBm]	Fixed 32	2xWi-Fi 2xLAA Wi-Fi vs LAA [indoor, outoor]	FTP 3 0.5 Mbyte	23 dBm	
[46]	CAT 3,4	CCA-ED: -55dBm	QoS Adaptive	Outdoor Indoor only coexistence 3GPP 1,2,3	FTP 3 0.5 Mbyte	18 dBm	
[47]	CAT 3,4	CCA-ED: -62dBm CCA-PD: -82dBm	Adaptive	Indoor standalone plain coexistence	FTP 0.5 Mbyte	18 dBm with LBT 23 dBm Without LBT	WaLT simulator CTS to self
[34]	CAT 2	CCA-ED: -62 dBm, -72 dBm		Outdoor - Mixed Indoor Outdoor [LTE vs Wi-Fi compared to 2x LTE or 2x Wi-Fi]		30 dBm	Channel selection STOCHASTIC 40MHz Bandwidth
[48]	CAT 2						LBT MARKOV
[49]	CAT 3	CCA-ED: -82 dBm E-CCA: 16 SLOTS	indoor building 2xWi-Fi Wi-Fi vs LAA	FTP 3 0.5 Mbyte		23 dBm	COT
[31]							MARKOV
[50]	CAT4	CCA-ED: -62 dBm	Adaptive on Channel Load	3GPP Indoor 2xWi-Fi LAA vs Wi-Fi	FTP 1 0.5 Mbyte	18 dBm	
[51]	CAT 4	CCA-ED: -77 dBm , -82 dBm	Dynamic [0,1] [0,2]	2x Wi-Fi vs Wi-Fi -LTE	Poisson	23 dBm AP and eNodeB	STOCHASTIC
[33]	CAT 2					UE 20 dBm STA 15 dBm	800 MhZ Bandwidth STHOCASTIC
[36]	CAT 3	CCA-ED: -62 dBm	32	Outdoor, indoor2xLAA- 2xWi-Fi, Wi-Fi vs LAA 3GPP 2,3	FTP 1 0.5 Mbyte	eNB 18dBm	BWSIM
[52]	CAT 4	CCA-ED: -62 dBm,-72 dBm,-82 dBm	[15,63] doubled with 80% of NACK	Indoor scenario Single Floor Building	FTP 3 0.5 Mbyte	18dBm	MCOT
[17]	CAT 1			Standalone, Wi-Fi +LTE-U 21-cell wrap-around dense hotspot		27 dBm	ABS - 40 MHz Bandwidth
[53]	CAT 1						ABS
[54]	CAT 1						ABS
[55]	CAT1				FTP 2 - Non full buffer Traffic Data	23 dBm	ABS
[56]	CAT 1						ABS 40 MHz Bandwidth
[57]	CAT 1						ABS
[58]	CAT 1						ABS Monte carlo MATLAB
[59]	CAT 1						ABS Monte carlo MATLAB

Thanks for the Attention!

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