LTE System Level Simulator Documentation, v1.0r295

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Abstract

This document contains documentation on how to use the Long Term Evolution (LTE) System Level simulator [1] as well as some insight on its structure and the assumptions that were made while developing it. This document relates more on how to actually use the simulator. The concept and the structure of the simulator is described in more detail in [2].

I. Foreword

The LTE system level simulator is published under a non-commercial academic use license. Please make sure that you understand the terms and conditions of the license before you use any of the available software packages. Would you require a license different to a non-commercial academic one please contact Christian Mehlführer or Josep Colom Ikuno.

The detailed license agreement for the LTE System Level simulator can be found in Section XII. Please read the license agreement carefully.

II. Running a simulation

The main file of the LTE Link Level Simulator is `LTE_sim_main.m`, though you may normally run the simulation through a batch file such as `LTE_sim_launcher.m`, which performs the following tasks:

- Loading a configuration file of choice. See Section III for a list of configurable parameters.
- Executing the `LTE_sim_main.m` main simulation file.

III. Simulation parameters

Below you can find a list of the parameters that can be configured in the `LTE_load_params` file:

A. General parameters

- `LTE_config.debug_level`: configures how much debug text output is shown. Options are:
  - `0`: no output.
  - `1`: basic output.
  - `2`: extended output.
- `LTE_config.show_network.`: configures how much plots are shown. Options are:
  - `0`: no plots shown.
  - `1`: show some plots.
  - `2`: show all plots, which includes one showing the moving User Equipments (UEs), which may slow down simulations significantly.
  - `3`: show also the plots of the generated microscale fading traces.
- `LTE_config.frequency.`: frequency in which the system is operating [Hz].
- `LTE_config.bandwidth.`: system bandwidth. Allowed values are 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz, and 20 MHz. This bandwidths are equivalent to 6, 15, 25, 50, 75, and 100 Resource Blocks (RBs) respectively.
- `LTE_config.UEs_only_in_target_sector`: defines whether UEs are created in the whole Region Of Interest (ROI) or just in the target sector. for the case where the UEs are just positioned in one sector, the other transmitters radiate at maximum power, just acting as interferers.
- `LTE_config.target_sector`: if UEs are only to be set in the target sector, this setting specifies which one that is. Set it to`center` for specifying the target sector to be the center one. `[eNodeB_id sector_id]` otherwise.
- `LTE_config.nTX`: number of transmit antennas. Used to generate the microscale fading trace.
- `LTE_config.nRX`: number of receive antennas. Used to generate the microscale fading trace.
- `LTE_config.tx_mode`: the transmission modes are defined in TS 36.213-820 Section 7.1, page 12 [3].

- `1`: single antenna.
- `2`: Transmission Diversity (TxD).
- `3`: Open Loop Spatial Multiplexing (OLSM). Spatial multiplexing with Large Cyclic Delay Diversity (CDD).
- `4`: Closed Loop Spatial Multiplexing (CLSM).
- `5`: Multiuser MIMO (not yet implemented).

- `LTE_config.seedRandStream`: in order to allow repeatability, it is possible to seed MATLAB's default random number generator. Set it to either `true` or `false`.
- `LTE_config.RandStreamSeed`: if the above is set to `true`, it specifies the seed. Seeds must be an integer between 0 and 2^{32} [4].
- `LTE_config.simulation_time_tti`: length of the simulation in Transmission Time Intervals (TTIs).
- `LTE_config.latency_time_scale`: the simulator keeps track of average UE throughput filtered with an exponential window. This averaged throughput is basically used by the proportional fair scheduler to obtain the average throughput. As in [5], the average throughputs $T_k(t)$ for each user k are updated using an exponentially weighted low-pass filter

$$T_k(t+1) = \begin{cases} \left(1-\frac{1}{t_c}\right)T_k(t) + \frac{1}{t_c}R_k(t), & k \in k^*, \\ \left(1-\frac{1}{t_c}\right)T_k(t), & k \notin k^*. \end{cases}$$

Whre k^* is the scheduled UE set and $R_k(t)$ the rate the k-th user got. t_c is the length of the window and is the value stored in `LTE_config.latency_time_scale`.

B. *Cache options*

- `LTE_config.cache_network`: whether you want to save the generated eNodeBs, Pathloss map and Shadow fading map to a `.mat` file. Either `true` or `false`. All cache options work in the following way:
  - cache=`true` and file exists: read cache file.
  - cache=`true` and file does not exist: create and then store data in cache file.
  - cache=`false`: do not use cache at all.
- `LTE_config.network_cache`: the name of the cache file. set it to `auto` if you want the simulator to assign a name automatically (eg. `data_files/network_1_rings_5m_res_TS25814_2.00GHz_freq.mat`).
- `LTE_config.delete_ff_trace_at_end`: since the microscala fading trace takes up large amounts of space, when doing the final `save` command, it is preferable to delete it, so as not to have too large result files.
- `LTE_config.UE_cache`: whether to save the user position to a file. Either `true` or `false`.
- `LTE_config.UE_cache_file`: the name of the cache file. set it to `auto` if you want the simulator to assign a name automatically (eg. `data_files/UE_cache_1rings_target_sector_only_20UEs_sector_20100301_114247.mat`).

C. *Network layout and macroscopic pathloss params*

- `LTE_config.network_source`: for now only the `generated` option is supported. Reading data from network planning tools in order to get real pathloss data may be supported in the future.
- `LTE_config.inter_eNodeB_distance`: in meters. When the network is generated, this determines the distance between the eNodeBs.
- `LTE_config.map_resolution`: in meters/pixel. Also the resolution used for initial user creation.
- `LTE_config.nr_eNodeB_rings`: number of eNodeB rings.
- `LTE_config.minimum_coupling_loss`: describes the minimum loss in signal [dB] between Base Station (BS) and UE or UE and UE in the worst case and is defined as the minimum distance loss including antenna gains measured between antenna connectors. Recommended values [6] are 70 dB for urban areas, 80 dB for rural.
- `LTE_config.macroscopic_pathloss_model`: sets what macroscopic pathloss model is to be used. Depending on the choice, different choices are available for `LTE_config.macroscopic_pathloss_model_settings.environment`. The available macroscopic pathloss models are:
  - `free space`: free space pathloss. More for testing purposes than for actual use with simulations. $L = \left(\frac{4\pi d}{\lambda}\right)^2$. d in meters.
  - `cost231`: COST231 pathloss model. The possible options for `LTE_config.macroscopic_pathloss_model_settings` are:
    - `urban micro`: microcell LOS and NLOS pathloss based on the COST231 Walfish-Ikegami model, see TR25.996 and COST 231 book.
    - `urban macro`: urban macrocell pathloss based on the COST 231 extended Hata model, see 3GPP TR25.996 and COST 231 book.

    - `suburban macro`: suburban macrocell pathloss based on the COST 231 extended Hata model, see 3GPP TR25.996 and COST 231 book.
  - `TS36942`: see [6] for more information. Possible environments are:
    - `urban`: $L = 40\left(1 - 4 \cdot 10^{-3} \cdot \mathrm{Dhb}\right) \cdot \log_{10}(R) - 18\log_{10}(\mathrm{Dhb}) + 21\log_{10}(f) + 80\,\mathrm{dB}$. Where R is the base station-UE separation in km, f the carrier frequency in MHz and Dhb is the base station antenna height in metres, measured from the average rooftop level.
    - `suburban`: $L = 69.55 + 26.16 \cdot \log_{10}(f) - 13.82 \cdot \log_{10}(\mathrm{Hb}) + [44.9 - 6.55 \cdot \log_{10}(\mathrm{Hb})]\log_{10}(R) - 4.78\left(\log_{10}(f)\right)^2 + 18.33 \cdot \log_{10}(f) - 40.94$. Where R is the base station-UE separation in km, f the carrier frequency in MHz and Hb is the base station antenna height above ground in metres.
  - `TS25814`: see [7] for more information. $L = I + 37.6 \cdot \log_{10}(R)$. Where R is the base station-UE separation in km and $I = 128.1$ when using a 2 GHz carrier and $I = 120.9$ for 900 MHz.
- `LTE_config.eNodeB_tx_power`: eNodeB's transmit poower, in Watts. Recommended by [**?**] are: 43 dBm for 1.25, 5 MHz carrier, 46/49 dBm for 10, 20 MHz carrier.

D. Shadow fading

- `LTE_config.shadow_fading_type`: specifies how the shadow fading is generated. Right now only `claussen` is supported. It generates a lognormal-distributed 2D space-correlated shadow fading map, as in [8].
- `LTE_config.shadow_fading_map_resolution`: map resolution for the shadow fading pathloss map (metres/pixel).
- `LTE_config.shadow_fading_n_neighbors`: specifies the number of neighbors the algorithm takes into account when space-correlating the shadow-fading mapts. Possible options are `4` and `8`, which use R_5 and R_9 [8] respectively.
- `LTE_config.shadow_fading_mean`: mean (μ) of the lognormal distribution.
- `LTE_config.shadow_fading_sd`: standard deviation (σ) of the lognormal distribution.
- `LTE_config.r_eNodeBs`: inter-site shadow fading correlation. The correlaton between the sectors in a site is fixed to 1 (same shadow fading map).

E. Microscale fading

Microscale fading trace to be used between the eNodeB and its attached UEs.

- `LTE_config.use_fast_fading`: whether microscale fading is to be used or not. Either `true` of `false`.
- `LTE_config.channel_model.type`: which PDP to use for the channel generation. Available options are:
  - `PedA`: ITU Pedestrian A channe [9].
  - `PedB`: ITU Pedestrian B channel [9].
  - `extPedB`: Extension of the ITU channel models for wideband (OFDM) systems [10].
  - `VehA`: ITU Vehicular A channel [9].
  - `VehB`: ITU Vehicular B channel [9].
- `LTE_config.channel_model.trace_length`: length of the channel trace in seconds. Be wary of the size you choose, as it will be loaded in memory.
- `LTE_config.pregenerated_ff_file`: where to save the channel trace. If the specified file exists, it will be loaded. For the `auto` or unexistent filename cases, a new trace will be generated. eg. `ff_60.0s_2x2_PedB_5.0MHz_5Kmph_20100205_`
- `LTE_config.recalculate_fast_fading`: whether generate the trace even if the file already exists (force a new trace).

F. UE settings

- `LTE_config.UE.receiver_noise_figure`: receiver noise figure in dB. Set to 9 dB [6].
- `LTE_config.UE.thermal_noise_density`: thermal noise density in dBm/Hz.
- `LTE_config.UE_per_eNodeB`: number of UEs per sector.
- `LTE_config.UE_speed`: speed at which the UEs move. In meters/second.

G. eNodeB settings

- `LTE_config.antenna_gain_pattern`: gain pattern of the antenna attached to each sector. Right now only 2D patterns are supported. Available options are:
  - `berger`: $A(\theta) = -\min\left[12\left(\frac{\theta}{70^\circ}\right)^2, 20\,\mathrm{dB}\right]$, $-180 \leq \theta \leq 180$.
  - `TS 36.942`: $A(\theta) = -\min\left[12\left(\frac{\theta}{65^\circ}\right)^2, 20\,\mathrm{dB}\right]$, $-180 \leq \theta \leq 180$ [6].
- `LTE_config.mean_antenna_gain`: antenna gain, in dB. Recommended values are: 15 dBi (rural area 900 MHz, urban area 2 GHz) and 12 dBi (urban area 900 MHz).

- `LTE_config.scheduler`: the type of scheduler to use. Supported schedulers are `round robin`, `best cqi` (Max C/I), and `proportional fair`. Please note that the proportional fair scheduler has not been throughly tested and may be buggy.
- `LTE_config.power_allocation`: only `homogeneous` is supported right now.

H. Uplink channel options

- `LTE_config.feedback_channel_delay`: uplink delay in TTIs. When set to 0 TTIs, only the Channel Quality Indicator (CQI) reports experience zero delay. ACK reports have a minimum delay of one TTI.
- `LTE_config.unquantized_CQI_feedback`: there is an option to send unquantized feedback, which is de-facto sending the measured Signal to Interference and Noise Ratio (SINR), as then afterwards the CQI is not mapped.

I. SINR averaging

- `LTE_config.SINR_averaging.algorithm`: what subcarrier averaging algorithm is to be used. For each option, the specific configuration parameters will vary. Possible options are [11]:
  - `EESM`: use Exponential Effective Signal to Interference and Noise Ratio Mapping (EESM). The following configuration parameters are needed:
    - `LTE_config.SINR_averaging.MCSs`: the Modulation and Coding Schemes (MCSs) defined in [12].
    - `LTE_config.SINR_averaging.betas`: the calibration β parameters that fit the EESM function to the Additive White Gaussian Noise (AWGN) Block Error Ratio (BLER) curves.
  - `MIESM`: use Mutual Information Effective Signal to Interference and Noise Ratio Mapping (MIESM). Please note that MIESM has not yet been throughly tested with the simulator. Some bugs may be present. A `.mat` file containing the Bit Interleaved Coded Modulation (BICM) capacity tables for the relevant modulations and bit mappings must be provided. One is included with the simulator:
    - `LTE_config.SINR_averaging.BICM_capacity_tables`: location of the BICM capacity tables. One is already provided: `data_files/BICM_capacity_tables_10000_realizations.mat`.

J. Saving of the results

- `LTE_config.results_folder`: folder where to save the results.
- `LTE_config.results_file`: results filename. `auto` assings a filename automatically.
  eg. `2.00GHz_freq_5.00_bw_200TTIs_20100304_103218_proportional_fair_r230.mat`.

K. Values that should not be changed

- `LTE_config.RB_bandwidth.`: Bandwidth of a RB. 180 KHz and should not be changed. It basically used for throughput calculations.
- `LTE_config.TTI_length`: length of a TTI (subframe) in seconds.
- `LTE_config.cyclic_prefix`: set to `normal`. It is used to calculate the number of available bits in each subframe, so it will not realistically reflect the effect of using another cyclic prefix length.
- `LTE_config.maxStreams`: maximum number of codewords per TTI. Set to two.

IV. Implementation Issues

A. How to read the pathloss maps

When reading the pathloss maps, the convention shown in Figure 1 has been used.

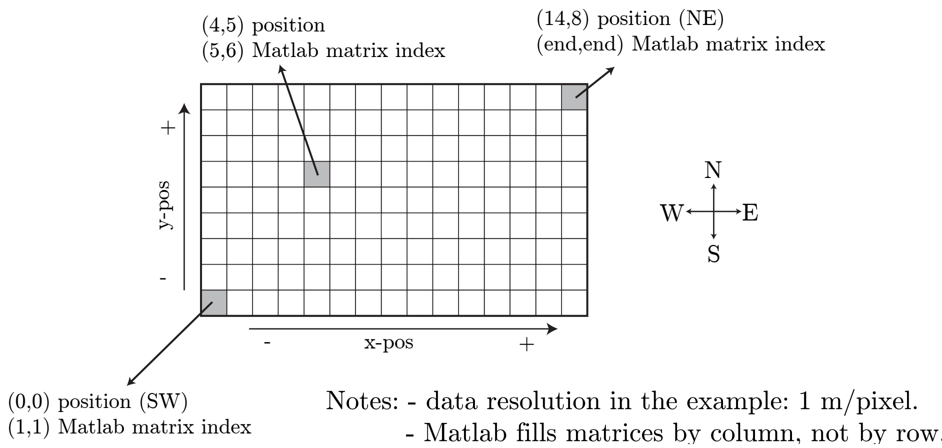


Fig. 1. Coordinates convention used in the LTE system level simulator.

It is because of this coordinate convention that in order to correctly display a pathloss map (without flipping it and with correct axes ticks) the following command is used:

```
imagesc([min_roi_x max_roi_x],[min_roi_y max_roi_y],pathloss_map);
set(gca,'YDir','normal');
```

B. Loading the BLER curves

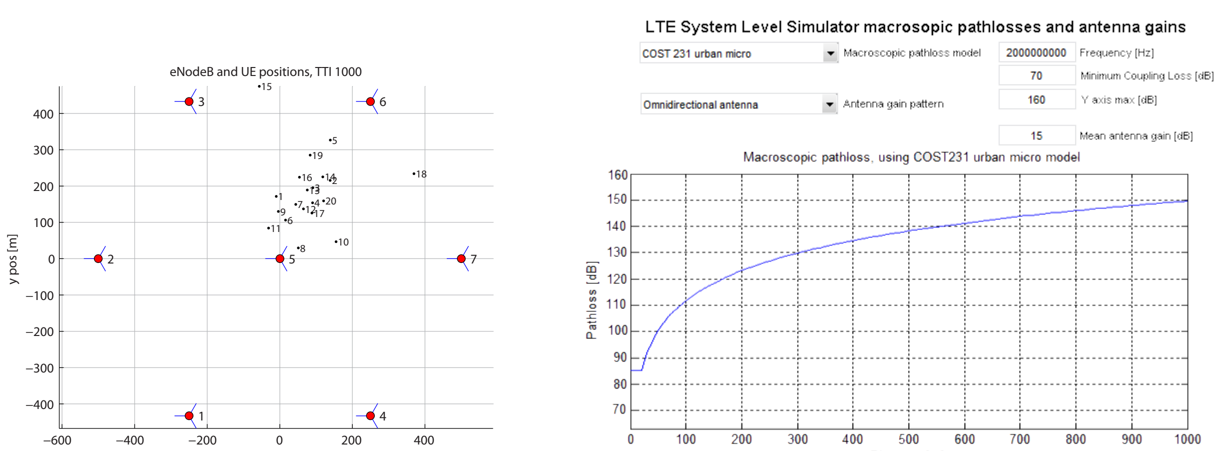
The BLER curve data files can be supplied to the simulator in the following forms:

- LTE link-level simulator [13] `.mat` results file.
- `.mat` file containing the following vector variables of equal length:
  - `SNR`: Signal to Noise Ratio (SNR) values.
  - `BLER`: BLER values.

V. Plotting Results

The `LTE_sim_results` provides some plotting of the result traces. The generated plots are the following:

- eNodeB and UE positions: self-explanatory. See Figure 2(a).
- `LTE_GUI_pathloss_antenna_info`: Graphical User Interface (GUI) that shows you the available macroscopic pathloss models and antenna gain patterns. Does not actually plot results. See Figure 2(b).



(a) UE position

(b) `LTE_GUI_pathloss_antenna_info` GUI

- Sector throughput and BLER: for every sector, shows the average throughput (summing both streams, when applicable) and overall BLER. If no users are assigned to the sector, `NaN` may be displayed as BLER.

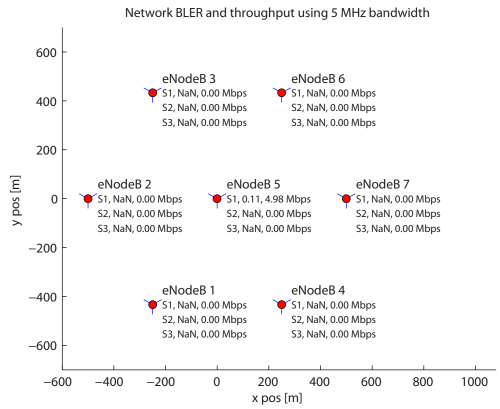


Fig. 2. Sector throughput and BLER

- `LTE_GUI_show_UE_traces`: this GUI shows you the following plots:
  - throughput and BLER over time. The blue line depicts the UE throughput in Mb/s for the selected stream and UE, as well as the BLER as measured by the ACK/NACK ratio (green line) and the BLER value applied by the link quality model. Although the system is calibrated to deliver BLERs$\geq$0.1, the actual results are influenced by the uplink delay and time variability of the channel.
  - UE position in the ROI.
  - sent CQI report for the selected RB and stream (blue), mean CQI for the whole frequency band (red) and CQI of to the Transport Block (TB) sent to the UE, if scheduled.
  - distribution of the CQIs for the selected UE and RB during the simulation time (blue), and of the TB CQIs (red).

  Note that all time-dependant data is averanged by using a rectangular window of configurable length.

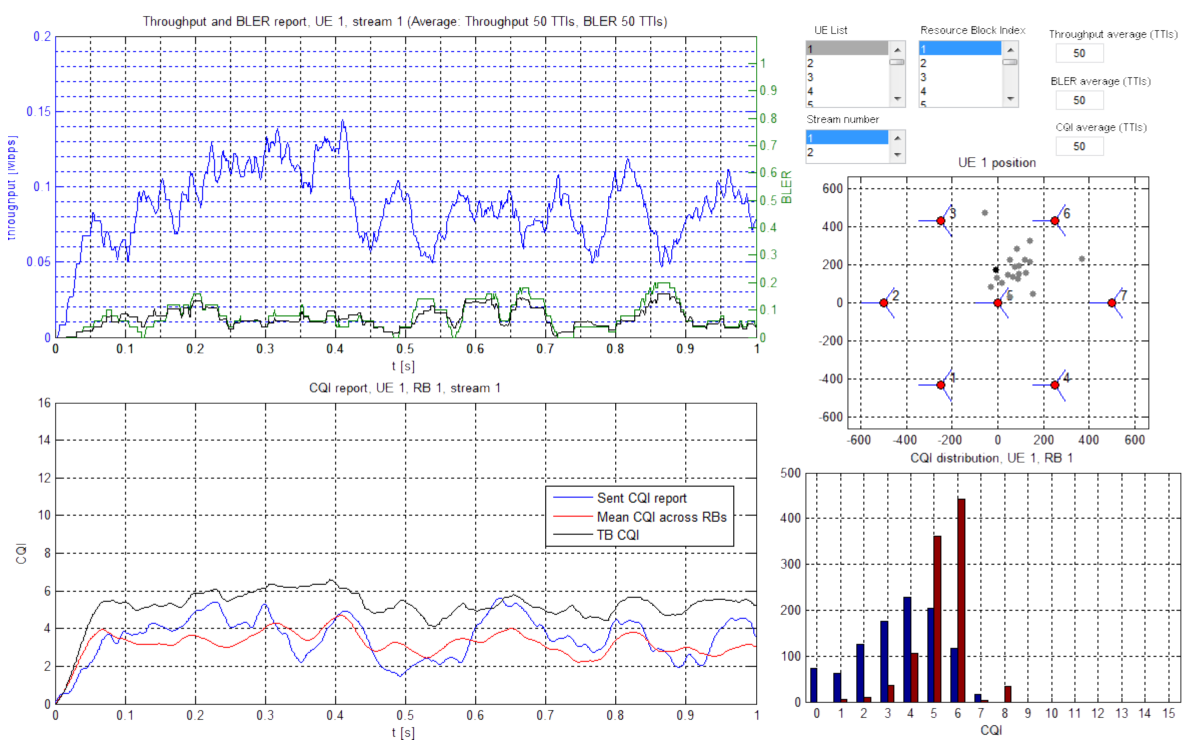


Fig. 3. `LTE_GUI_show_UE_traces` GUI

- `LTE_GUI_show_cell_traces`: GUI depicting the cell traces for the selected eNodeB/sector pair. Contains the following figures:

- graphical depiction of the RB allocation for the selected TTI.
- evolution of the number of assigned RBs to each UE during the selected TTI range.
- throughput and BLER for the selected stream number. Throughput and BLER are averaged using a rectangular window of configurable length. In order to make the post-processing faster, the cell throughput is calculated with the ACKed data from the UEs instead of checking the throughput of every attached UE. Thus, the uplink delay makes you lose the value for some TTIs.

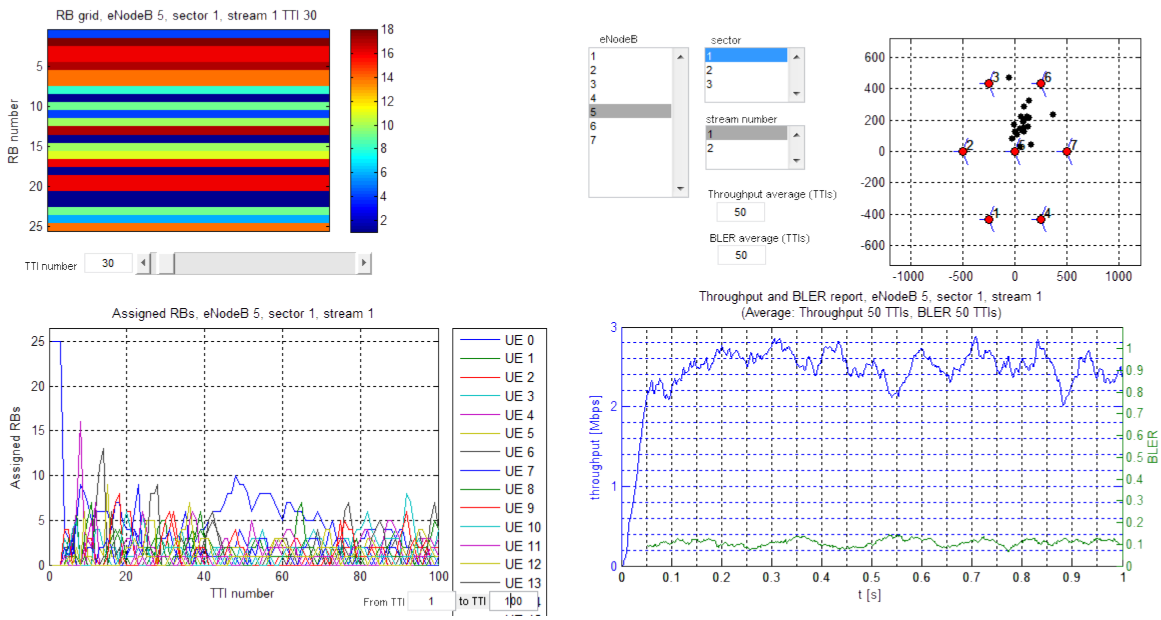


Fig. 4. `LTE_GUI_show_cell_traces` GUI

VI. Reproducing the results/plots presented on a paper

One of the main points of the simulator is to allow you to reproduce and review our results, as well as the algorithms that produce them. For each of the following publications, a set is configurable that will reproduce the results in the corresponding paper:

- J. C. Ikuno, M. Wrulich, and M. Rupp, System level simulation of LTE networks, in Proc. 2010 IEEE 71st Vehicular Technology Conference, Taipei, Taiwan, May 2010 [2]:
  In the `reproducibility/VTC2010` forlder, the `plot_ECDFs` script allows you to reproduce the CDF plots shown in the paper using the already pre-processed results. If you would like to reproduce the simulation traces from which the result files were extracted (∼8 GB of traces), you can do so by moving the `LTE_sim_VTC`, `LTE_sim_batch_2x2_*_*`, and `LTE_load_params_2x2_*_*` scripts to the root folder of the simulator and executing the `LTE_sim_VTC` script. The result files can then be post-processed with the `LTE_plot_UE_throughput_CDF` script (it must be also copied to the simulator root folder). Please note that you will have to adapt the folder-related variables to suit where the result files are located.
  The simulations from [2] were done with the following basic configuration (Table I):

Parameter	Value
Frequency	2.0 GHz
Bandwidth	5 MHz
Thermal noise density	-174 dBm/Hz
Receiver noise figure	9 dB [6]
nTX×nRX antennas	2×2
TX mode	TxD and OLSM
Simulation length	500 TTIs
Number of simulations	200 per scenario
Inter eNodeB distance	500 m
Minimum Coupling Loss	70 dB [6]
Macroscopic pathloss	$128.1 + 37.6\log_{10}(R)$ [7]
Shadow fading	lognormal, space-correlated [8], $\mu = 0, \sigma = 10\,(dB)$
Shadow fading correlation	Inter-site: 0.5, Intra-site: 1 [6]
eNodeB TX power	43 dBm [6]
Microscale fading	PedB uncorrelated, time-correlated [14]
UEs position	Homogeneous. UEs located in target sector only, 20UEs/sector
UE speed	5 KM/h
BS Antenna pattern	$A(\theta) = -\min\left[12\left(\frac{\theta}{65^\circ}\right)^2, 20\,\mathrm{dB}\right],\ -180 \leq \theta \leq 180$ [6]
BS antenna gain	15 DBi [6]
Scheduler	Round Robin, Max C/I (Best CQI)
Subcarrier averaging algorithm	EESM
Uplink delay	3 TTIs

TABLE I
CONFIGURATION PARAMETERS USED FOR [2]

VII. CHANGELOG

- v.1.1r295, 2010-04-12.
  - Updated AWGN BLER curves to more precise ones.
  - Fixed bug that caused the simulator to crash when storing the exponentially-averaged throughput when using less than two data streams.
  - Fixed an error in the generation of the OLSM traces. The used CDD D matrix was erroneously $\begin{bmatrix} 1 & 0 \\ 0 & e^{-j2\pi/2} \end{bmatrix}$ instead of $\begin{bmatrix} 1 & 0 \\ 0 & e^{-j2\pi i/2} \end{bmatrix}$. So it was not changing over time.
- v.1.0r247, 2010-03-15.
  - First publicly available version of the LTE System Level Simulator.

VIII. REFERENCING

A version of the LTE System Level Simulator paper is available in our publication data-base **here**.

If you are using the simulator for your scientific work, please use the refence below:

```
@InProceedings{VTC2010,
  author =        {Josep Colom Ikuno and Martin Wrulich and Markus Rupp},
  title =         {System level simulation of {LTE} networks},
  booktitle =     {Proc. 2010 {IEEE} 71st Vehicular Technology Conference},
  month =          may,
  year =           2010,
  address =       {Taipei, Taiwan},
  url =           {http://publik.tuwien.ac.at/files/PubDat_184908.pdf},
}

J. C. Ikuno, M. Wrulich, and M. Rupp, System level simulation of LTE networks,
in Proc. 2010 IEEE 71st Vehicular Technology Conference, Taipei, Taiwan, May 2010. [Online]
Avaialable: http://publik.tuwien.ac.at/files/PubDat_184908.pdf
```

IX. KNOWN ISSUES

- The LTE simulators make use of the new Object-Oriented capabilities of Matlab (available since R2008a), the simulators will not run under older Matlab releases without extensive changes.
- Please note that MEX-files generated using Microsoft Visual C++ 2008 require that Microsoft Visual Studio 2008 run-time libraries be available on the computer they are run on. The runtime files can be downloaded **here** (x86) or **here** (x64). If you would need to compile for another arquitecture, the `LTE_aux_mex_files` script can be used.

X. MAILING LIST

If you want to receive information about future updates you can subscribe to our LTE simulator mailing list **here**. Note that you can change the display language to english in the selection panel to the right.

XI. The People (so far) behind the development of the LTE System Level simulator

- Josep Colom Ikuno
- Markus Rupp
- Stefan Schwarz
- Martin Taranetz
- Martin Wrulich

XII. License agreement

F. Limitation of liability

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