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Table of contents

0. Executive Summary	7
1. Introduction and Overview of CWiND Simulation Platform	8
2. LTE Frame-Level Simulator (LTE-FLS)	10
3. LTE Packet-Level Simulator (LTE-PLS)	11
<i>3.1 Simulation Details</i>	<i>11</i>
<i>3.2 Traffic modelling</i>	<i>13</i>
<i>3.3 Mobility modelling</i>	<i>15</i>
4. Conclusions	16
References	17

List of Figures

[Figure 1 CWiND simulation platform structure](#) 9

[Figure 2. Support of 3D GIS and building](#) 9

[Figure 3. LTE protocol architecture \(downlink, transmitter side\)](#) 11

[Figure 4: Data flow between protocol layers](#) 13

List of Tables

No table of figures entries found.

0. Executive Summary

This purpose of this deliverable is to provide a system level simulator that can be used to investigate LTE (Long Term Evolution) femto/macro scenarios. In this project, an LTE simulator has been developed on the basis of the CWiND (Centre for Wireless Network Design) WiMAX simulator as they use similar technologies.

The LTE simulation module supports both frame-level and packet level simulations, both for downlink only at the moment.

The frame-level simulator (FLS) enables less detailed traffic modelling, and has a lower run-time complexity than the packet-level simulator (PLS). The individual packets are not simulated, and the User Equipments (UEs) are assumed to always have data to be transmitted. The lower run-time complexity makes it suited for evaluating scenarios and comparing new procedures where a high number of cells and users need to be simulated. The user traffic can be modeled either as a fixed number of Resource Block (RB) requirement or by a fixed bandwidth requirement. The primary performance indicator used is the UE throughput, which is calculated based on the selected Modulation and Coding Scheme (MCS) of its assigned RBs. The selection of MCS for a group of sub-carriers is based on the required BLER (Block Error Rate) and the effective Signal to Interference plus Noise Ratio (SINR), using a look up table to save time.

The PLS enables more detailed traffic modelling, i.e. the traffic can be defined on the packet level. It does detailed simulation of the LTE downlink data plane. It implements the key protocol functional blocks (e.g., PDCP, RLC, MAC, HARQ and PHY) following the 3GPP Release 8 recommendations.

1 Introduction and Overview of CWiND Simulation Platform

The CWiND simulation platform, which has over a quarter million lines of codes mainly written in C++, is one of the most powerful mobile network system level simulators (SLSs) that are developed by a university group. The development of CWiND simulation platform started in 2006. The development of the LTE system level simulator was supported by the iPLAN project. In addition, since 2009, the iPLAN project also helped the enhancement of CWiND core (i.e., the Graphic User Interface (GUI) for the simulator), WiMAX and HSPA modules, as well as the APIs that link radio propagation models, performance analysis and various network modules.

As shown in Fig. 1, the key features of the CWiND simulation platform are as follows:

- It supports heterogeneous radio access technologies (RATs) such as WCDMA/HSPA/LTE/WiMAX and heterogeneous access points e.g., NB/HNB, eNB/HeNB, i.e., both macro-cell and femtocells.
- It supports both outdoor full 3D GIS (3D view & operation, etc) and indoor 3D building data (Fig. 2). Its 3D outdoor and indoor capability makes it well suited to evaluate adaptive spatial multiplexing as well as transmit diversity of MIMO and make it well suited to study femto/macro scenarios. In addition, traffic maps are supported on top of GIS.
- It supports antenna formats from various manufacturers. It is linked to various radio propagation models, such as empirical (e.g., COST231-Hata) and deterministic models based on Finite Difference Time Domain (FDTD) and 3D ray tracing and launching algorithms. In addition, channel measurement data can be input to the simulator to carry out propagation model tuning and validation.
- It has a good GUI (CWiND Core) to support user interactions with the simulator. Unlike the radio propagation and simulation modules, the CWiND core is developed in Matlab. Apart from the GUI, users can also write Matlab M files to interact with the simulator. Such a design facilitates both computational efficiency and easy use.
- It supports both static Monte Carlo and dynamic simulation; hence, RRM and MM can be well studied.
- It outputs various system performance metrics (e.g., throughput, connection rate, outage probability, handover success rate, etc.) and problem states such as frequency collision, pilot pollution, etc., in graphs and tables.
- It supports parallel and distributed computing (e.g., Grid computing), various computational intensive modules such as radio propagation, simulation and optimisation can be done in parallel computers or the Grid (it evolved to cloud computing).

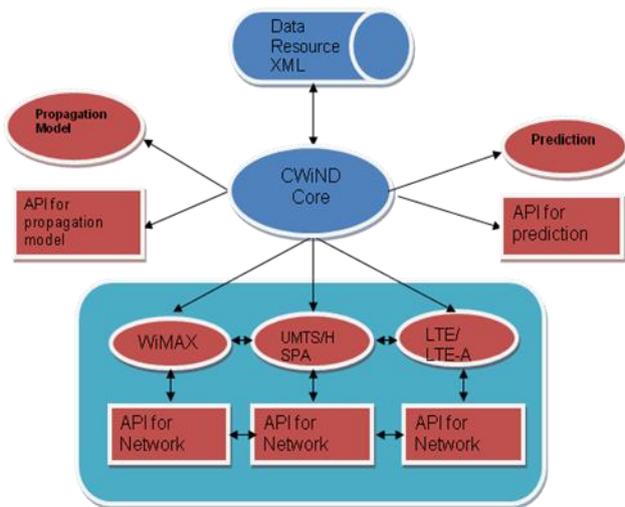


Figure 1 CWiND simulation platform structure

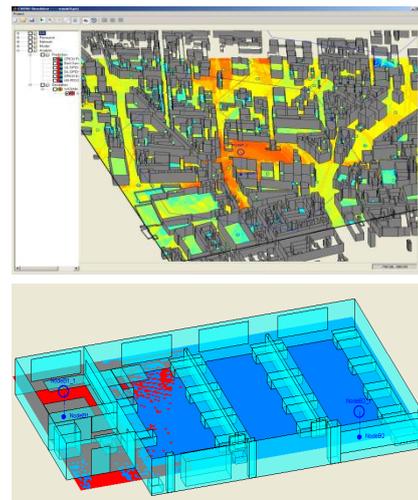


Figure 2. Support of 3D GIS and building

For more information about the general features of the CWiND simulation platform, refer to Prof. Jie Zhang's mid-term review presentation on behalf of UoB.[1]

In the next two sections, two LTE system level simulators will be introduced, i.e., LTE Frame-Level Simulator (LTE-FLS), LTE Packet-Level Simulator (LTE-PLS).

2 LTE Frame-Level Simulator (LTE-FLS)

This simulator enables less detailed traffic modeling, but on the other hand it has a lower run-time complexity than the packet-level simulator.

In this context frame-level means, that the individual packets are not simulated, but the user terminals are assumed to always have data to be transmitted. Currently this simulator is downlink only.

The relatively lower run-time complexity makes this simulator especially suitable for evaluating scenarios and comparing new procedures where a high number of cells and users need to be simulated.

The user traffic can be modeled either as a fixed number of Resource Block (RB) requirement or by a fixed bandwidth requirement. The latter is equivalent to the full buffer model. That is for each user terminal there is always data to be transmitted, and the amount of it is given by the bandwidth requirement.

The primary performance indicator used is the user throughput. The throughput of a user is calculated based on the selected Modulation and Coding Scheme (MCS) and the Signal to Interference plus Noise Ratio (SINR) of its assigned RBs. How these resources are allocated to the users is usually a degree of freedom, but for femtocells a few allocation strategies are already provided: random assignments, measurement report based assignment [2][11], min-power allocation [3].

Depending on the purpose of the simulation the target can be either the maximization of the throughput or guaranteeing a minimum throughput for users.

Dynamic Event Scheduler

The basis of this simulator is an event-driven simulation engine. This is used to model the time in the dynamic simulations. Time is represented as series of events. An event is described by the time when it takes place, and an action.

The events are stored in a priority queue data structure, which enables the efficient extraction of the next event, i.e. the one with the earliest occurrence time. The events are processed in order of their occurrence time. When an event gets processed its action is executed. After this the event data structure either gets de-allocated, or the event is rescheduled for a later time point. The latter allows for the efficient implementation of recurring events.

Events are used for example to make a user to appear, disappear or move in the scenario. Also events are used to implement e.g. the self-organization procedures of femtocells.

3 LTE Packet-Level Simulator (LTE-PLS)

The PLS enables more detailed traffic modelling, i.e. the traffic can be defined on the packet level. It does detailed simulation of the LTE downlink data plane, on the expense of a higher run-time complexity compared to the frame-level simulator.

3.1 Simulation Details

In Fig. 3, those LTE transmit and receive procedures that are shaded are implemented in the LTE-PLS, i.e., it implements the key protocol functional blocks (e.g., PDCP, RLC, MAC, HARQ and PHY) following the 3GPP Release 8 recommendations.

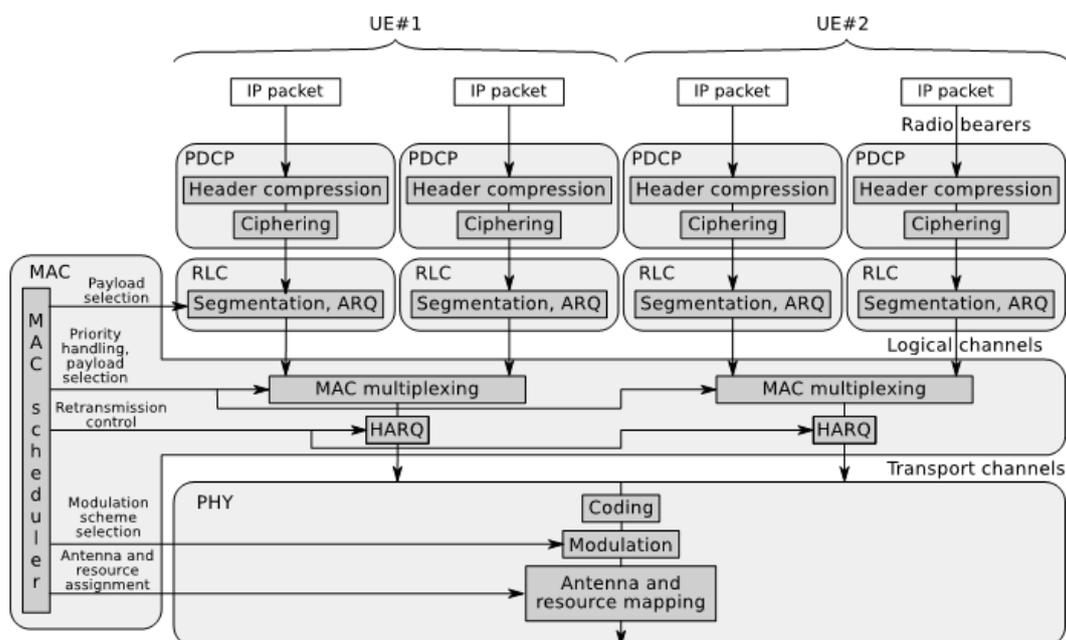


Figure 3. LTE protocol architecture (downlink, transmitter side) [4][5]

PDCP Simulation

The Packet Data Convergence Protocol (PDCP) layer, which does header compression and ciphering is simulated by reducing the size of the data packets by a given amount.

RLC Simulation

Radio Link Control (RLC) is responsible for segmentation, concatenation, retransmission handling, and in-sequence delivery to higher layers.

The RLC layer can operate in two modes: unacknowledged and acknowledged. Acknowledged mode is used for traffic which is sensitive to packet loss, while unacknowledged mode is used when delay is more important than packet loss, like in the case of VoIP. This also

means that there are as many RLC queues per user terminal, as many service types (radio bearers) are used by the user terminal (Figure 3).

In unacknowledged mode the transmit side RLC entities perform only segmentation and concatenation, that is they create appropriately sized RLC Packet Data Units (PDUs) from the RLC Service Data Units (SDUs) (Figure 4). The latter corresponds to the IP packets, which are compressed and encrypted by the Packet Data Convergence Protocol (PDCP). The decisions about how much data to put in an RLC PDU are made by the scheduler.

The receiver side RLC reassembles the parts and ensures in order delivery. In acknowledged mode additionally to these retransmissions can be performed by the RLC.

MAC Simulation

The Medium Access Control (MAC) layer handles Hybrid Automatic Repeat Request (HARQ) retransmissions and scheduling.

The transmit side MAC entity does the multiplexing of the output of the RLC queues of one user terminal, by taking into account priorities between them. In other words the MAC entity creates MAC SDUs from the RLC PDUs of different RLC entities. After the addition of a header these MAC SDUs will form the Transport Blocks (TBs) (Figure 4).

Every millisecond the scheduler will build these TBs for each terminal and map them to the RBs of a subframe. That is where the multiplexing of the traffic of different terminals happens.

The scheduler works in two stages. First, a time-domain scheduler is run to select which terminals should transmit in the current subframe, then a frequency-domain scheduler is used to map the TBs to RBs. The task of the time-domain scheduler is to fulfil the QoS requirements of the services. While the task of the frequency domain scheduler is to take advantage of the channel variations between terminals and preferably schedule transmissions to a terminal on those RBs where channel conditions are advantageous. The channel conditions are estimated based on channel-status reports from the terminals.

Currently the time-domain scheduler does blind equal throughput scheduling while the frequency-domain scheduler does throughput-to-average scheduling [6], but it is easy to implement new scheduling strategies or extend this one.

The scheduler also needs to take into account which terminals have re-transmissions. Retransmissions have priority over new transmissions, that is a terminal having both a TB to be retransmitted and data for new transmission will be scheduled for retransmission. Retransmissions need to be done with the same transport format as the original transmission, therefore it can be calculated how many RBs are needed for them, while the remaining RBs can be divided up among the terminals with new transmissions.

The MCS selection is handled by the MAC layer too, and it is done based on the channel-status estimations.

The receiver side MAC entity checks if it is possible to decode the received TBs. If not it requests a retransmission. The negative or positive acknowledgments of the receiver are altered to the opposite with a small probability, to simulate their unreliability [4]. This causes that some TBs are not transmitted successfully without the sender side being aware of it. The resulting residual error rate can be offset by the retransmissions of the RLC layer.

PHY Simulation

LTE HARQ utilizes soft-combining with Incremental Redundancy (IR)[7]. This means that in each retransmission of a TB new redundancy bits are added from the channel encoder. The decoder combines all the transmissions and decodes the data at a lower code rate. The gains of the successive retransmissions are calculated based on a low-complexity model presented in [8].

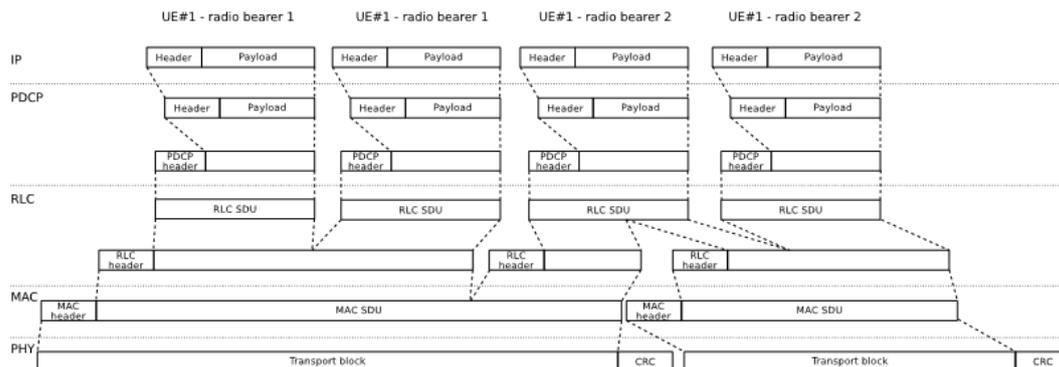


Figure 4: Data flow between protocol layers [4]

3.2 Traffic modelling

User Generation

In case of macrocell scenarios traffic maps are used for user generation. These mark a given area of the scenario and either have an associated user density or an associated user count.

In case of femtocell scenarios the users are put inside the designated houses. The number of users per femtocell is usually limited to 4.

Traffic Generation

In the simulator the following types of traffic generators have been implemented. These are used to feed the simulator with data packets. They follow the recommendations of NGMN [9] found in [10].

FTP

An FTP session is a series of file transfers separated by waiting times. The size of the file to be transferred is a probability variable with truncated log-normal distribution (mean: 2MB, standard deviation: 0.722MB, maximum: 5MB). The waiting time is an exponentially distributed probability variable (mean: 180 s).

The arrival of the packets comprising the file to be transferred is determined by a simplified model of the TCP protocol. The packets are created every Round-Trip Time (RTT) interval. The amount of data sent at each interval is limited by the Congestion Window (CWND). Initially the CWND is the double of the Maximum Segment Size (MSS). The size of the CWND increases by $MSS^2/CWND$ for every positive acknowledgment, and gets halved for a negative

one. The amount of data sent at each interval is packetized by respecting the limit imposed by the MSS (536 bytes).

Web Browsing

Using HTTP Web browsing traffic is modelled as a transfer of a main web-page followed by the transfer of the embedded objects (e.g. pictures) of the web page. The size of the main web-page is modelled with a truncated log-normal distribution (mean: 10710 bytes, standard deviation: 25032 bytes, minimum: 100 bytes, maximum 2Mbytes). The size of the embedded objects is also modelled with a truncated log-normal distribution, but with different parameters (mean: 7758 bytes, standard deviation: 126168 bytes, minimum: 50 bytes, maximum: 2Mbytes). The number of the embedded objects is modelled by a truncated Pareto distribution (mean: 5:64, maximum: 53). The transfer of all these objects is performed using the TCP model introduced before. After the transfer of the main web-page parsing it takes some time - exponentially distributed (mean: 0:13 s) – then the embedded objects are transferred too. After this is finished the next page is requested after some reading time, which is also exponentially distributed (mean: 30 s).

Video Streaming

The video stream consists of frames arriving at regular time intervals (100ms). Each frame is coded as a fixed number of slices (8), which each form a separate packet. The size of these packets has a truncated Pareto distribution (mean: 100 bytes, maximum: 250 bytes). The delay between the packets is modelled also with a truncated Pareto distribution (mean: 6ms, maximum: 12:5ms).

VoIP

VoIP traffic is modelled with a two-state Markov chain. The active state corresponds to the periods of speech and the inactive state to the periods of silence. The probability of changing state from inactive to active and from active to inactive is set to 0:01. The model is assumed updated at the speech encoder frame rate $R = 1/T$, where T is the encoder frame duration (20ms).

We assume an Adaptive Multi-Rate (AMR) 12.2 audio codec, therefore when in active mode a voice packet of 40 bytes is generated every 20ms.

While in inactive mode a SID packet of 15 bytes is generated every 160ms. These packets are used to generate a comfort noise in order to avoid confusing the user between being disconnected or waiting for new data packets.

Session Generation

The traffic generation framework also provides adaptors for the above described traffic generators. Using these one can model that a user is utilizing a given service only at different times or that one user uses more than one type of service e.g. web browsing and video streaming at the same time.

Using these service definitions user types can be defined. These user types can be utilized when defining traffic maps (Section 3.2) by associating different densities to them.

3.3 Mobility modelling

For the outdoor pedestrian users a waypoint mobility model was implemented. The improvements over the basic waypoint model are the addition of deviations in speed and direction which model the dynamics of human walk. The waypoints can be either given as input, or randomly generated.

4 Conclusions

In this deliverable, two LTE system level simulators are presented. The simulator was completed on time (however, the delivery of the report was delayed). The LTE system level simulators laid a very good foundation to study interference in femto/macrocell environment, auto-configuration algorithms for femtocells and handover algorithms between femto and macro-cells.

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