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SIMULATING THE LONG TERM EVOLUTION LINK IN MULTI-CORE PROCESSORS
SIMULIMI I LINKUT NË EVOLUIMIN AFATGJATË NË PROCESORËT ME MULTI-CORE

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PERMBLEDHJE

Kërkimet dhe zhvillimet e algoritmeve për përpunimin e sinjalit në UMTS Long Term Evolution kërkojnë një ambient simulimi real, fleksibël dhe në përputhje me standardet e përcaktuara. Për të bërë krahasimin me rezultatet e arritura nga grupet e tjera kërkimore, simulatori duhet të jetë pa pagesë. Në këtë punim paraqitet simulimi në MATLAB i shtresës fizike të kanalit marrës LTE, si dhe aplikacionet kërkimore të ndryshme që mund të realizohen nga ky simulator. Simulatori ofron mundësi simulimesh të një kanali marrës të vetëm, të një qelize me shumë përdorues, si dhe të shumë qelizave me shumë përdorues. Duke përdorur "Parallel Computing Toolbox" në MATLAB, simulatori ekzekutohet me efikasitet në procesor me "multi-core" duke reduktuar ndjeshëm kohën e simulimit.

Fjalët kyce: LTE, simulator, link, përpunim në paralel.

SUMMARY

Research and development of signal processing algorithms for UMTS (Universal Mobile Telecommunications System) LTE (Long Term Evolution) requires a realistic, flexible, and standard-compliant simulation environment. To facilitate comparisons with work of other research groups such a simulation environment should ideally be free of charge. In this paper, we present a MATLAB-based downlink physical-layer simulator for LTE. We identify different research applications that are covered by our simulator. Depending on the research focus, the simulator offers to carry out single-downlink, single-cell multi-user, and multi-cell multi-user simulations. By utilizing the Parallel Computing Toolbox of MATLAB, the simulator can efficiently be executed on multi-core processors to significantly reduce the simulation time.

Key words: LTE, simulator, link, parallelism

LTE was standardized by 3GPP (3rd Generation Partnership Project) as the successor of the UMTS. The targets for downlink and uplink peak data rate requirements were set to 100 Mbit/s and 50 Mbit/s, respectively, when operating in a 20MHz spectrum allocation. The LTE downlink transmission scheme is based on OFDMA (Orthogonal Frequency Division Multiple Access) which converts the wide-band frequency selective channel into a set of many flat fading subchannels. The flat fading subchannels have the advantage that even in the case of MIMO (Multiple Input Multiple Output) transmission optimum receivers can be implemented with reasonable complexity, in contrast to WCDMA (Wideband Code Division Multiple Access) systems. OFDMA additionally allows for frequency domain scheduling, typically trying to assign only "good" subchannels to the individual users. This offers large throughput gains in the downlink due to multi-user diversity [1,2]. Another feature of LTE is the X2-interface between base-stations. This interface can be used for interference management aiming at

decreasing inter-cell interference. The standard only defines the messages exchanged between the base stations while the algorithms and the exact implementation of the interference mitigation remain vendor specific and are currently a hot topic in research, see for example [3,4].
We present a Matlab-based LTE physical layer simulator and investigate the gains in execution time when parallelizing the simulation. The simulator implements a standard compliant LTE downlink with its main features being AMC (Adaptive Modulation and Coding), MIMO transmission, multiple users, and scheduling. Most parts of the LTE simulator are written in plain Matlab-code. Only computationally intensive functions like soft-sphere or channel decoding are implemented in ANSI-C as MEX functions.

MATERIAL AND METHODS

Depending on the application we distinguish between three different classes of simulations that differ greatly in computational complexity.

Single-Downlink

The single-downlink simulation only covers the link between one base-station and one user-equipment. Such a set-up allows for the investigation of channel estimators, channel tracking,
channel prediction, synchronization algorithms, for example [5,6], MIMO gains, AMC feedback including feedback mapping optimization, for example [7], receiver structures [8], neglecting interference and impact of the scheduling, modelling of channel encoding and decoding [9], and physical layer modelling [10,11] crucial for system level simulations.

Single-Cell Multi-User

The single-cell multi-user simulation covers the links between one base-station and multiple users. This set-up now additionally allows for the investigation of receiver structures, taking the influence of the scheduling into account, multi-user precoding [12], resource allocation and scheduling, and multi-user gains.
In case of receiver structure investigations, the computational complexity of the simulation can be reduced by only evaluating the user of interest. For all other users only the AMC feedback has to be calculated to enable a functional scheduler.

Multi-Cell Multi-User

The multi-cell multi-user simulation is by far the most computationally demanding scenario and covers the links between multiple base-stations and multiple users. This set-up allows for the realistic investigation of interference-aware receiver techniques [13,14], interference management, including cooperative transmissions [15], and network based algorithms like joint resource allocation and scheduling.
Note that the last two proposed investigations require vast amounts of computational effort. This effort can be greatly reduced by employing system-level simulators [16,17] in which the physical layer is described by an analytic model.

EXPLOITING PARALLELISM

An efficient use of multiple cores therefore requires parallel processing in simulations. A very convenient way to parallelize Matlab simulation code is to utilize Mathworks' Parallel Computing Toolbox. Since almost all simulations carried out in the LTE physical layer simulator are performed over varying signal-to-noise ratios, we decided to utilize the *parfor (*parallel for) loop. Matlab provides the command *matlabpool()* specifying the number of cores and file dependencies. The *parfor loop* requires some overhead for distributing the code to individual cores of a processor and also for collecting the results. The performance increase due to the parallel execution was tested on an Intel Core 2 Quad Q6600 (2.4 GHz) processor. We simulated a SISO (Single Input Single Output) LTE downlink transmission over an AWGN (Additive White Gaussian Noise) channel (1000 subframes transmitted in an SNR (Signal Noise Ratio) range of 0 to 15 dB with 0.5 dB steps). Such a simulation (which runs rather fast because of its low complexity) takes about 1.3 hours when utilizing only one core of the quad core processor. The simulation speeds up by a factor of 1.9 and 3.7 when two and four cores are used. Thus, almost perfect parallelization is achieved.

Parameter	Setting
Transmission scheme	SISO
Bandwidth	1.4 MHz
Nr. of users	1
Simulated TBs	10'000
Channel knowledge	Perfect
Max. HARQ retransmissions	0, 1, 2 and 3

Table 1. SISO AWGN Simulation Settings

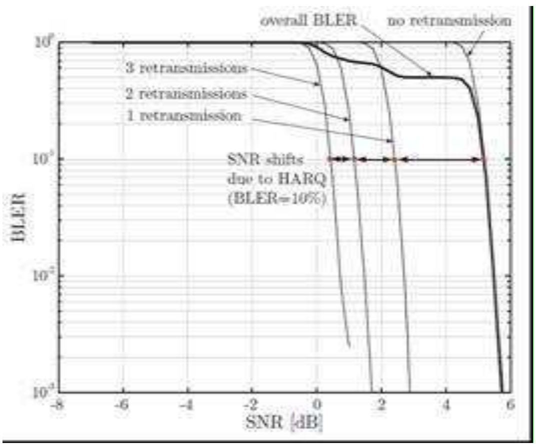

Figure 1. Resulting BLER at CQI=7 for different number of allowed retransmissions.

LTE PHYSICAL LAYER PERFORMANCE RESULTS AND DISCUSSIONS

The common simulation settings for the results presented are summarized in Table 1. The SNR in the simulator is defined as the subcarrier SNR, that is the sum of the data subcarrier signal powers divided by sum of the noise powers received on all data subcarriers.

BLER Results

To obtain the BLER (Block Error Ratio) and throughput for the MCS (Modulation and Coding Scheme) corresponding to each CQI (Channel Quality Indicator) value, AWGN simulations were performed. The MCS determines both the modulation alphabet and the ECR (Effective Code Rate) of the channel encoder. Simulations show that the BLER results of CQIs 1-15 without using HARQ (Hybrid Automatic Repeat Request) are spaced approximately 2 dB from each other. When allowing retransmissions, BLER curves are obtained as shown in Figure 1.

In LTE, adaptive modulation and coding has to ensure a BLER value smaller than 10 %. The SINR (Signal to Interference plus Noise Ratio) -to-CQI mapping required to achieve this goal can be obtained by plotting the 10% BLER values as shown in Figure 2. AWGN BLER curves are utilized in system level simulations to obtain the error probability of a received block as a function of the SINR and the MCS. When working with frequency-selective channels, an SINR averaging algorithm is required in order to compress the subcarrier SINR values into an effective SINR which is subsequently mapped to a CQI. Non-linear averaging methods such as the EESM (Exponential Effective SINR Mapping) [18,20] are usually employed to perform this compression.

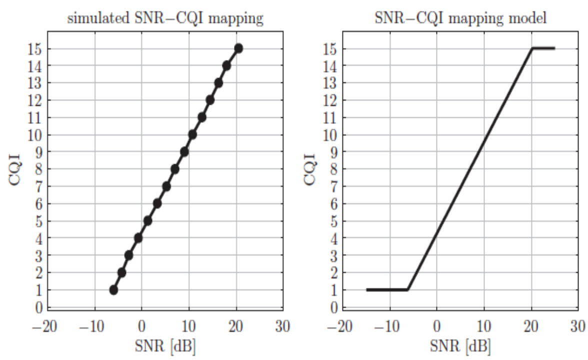

Figure 2. CQI mapping. BLER=10% points from the BLER curves (left) and SINR-to-CQI mapping function (right)

Throughput Results

The throughput results are compared to the system capacity C of an AWGN channel calculated according to:

$$C = FB\log_2(1+SNR) \qquad (1)$$

Here, SNR is the Signal to Noise Ratio, B the bandwidth occupied by the data subcarriers, and F a correction factor. The bandwidth B is calculated as:

$$B = \frac{N_{sc} \cdot N_s \cdot N_{rb}}{T_{sub}} \quad (2)$$

where: $N_{sc} = 12$ is the number of subcarriers in one RB (Resource Block), N_s is the number of OFDM symbols in one subframe (usually equal to fourteen when the normal Cyclic Prefix (CP) is set), N_{rb} is the number of RBs that fit into the selected system bandwidth (for example 6 RBs within a 1.4 MHz system bandwidth), and T_{sub} is the duration of one subframe equal to 1 ms. The transmission of an OFDM signal requires also the transmission of a CP to avoid inter-symbol interference and the reference symbols for channel estimation. Therefore, the well-known Shannon formula is adjusted in Equation (1) by the factor F . This factor F accounts thus for the inherent system losses and is calculated as:

$$F = \underbrace{\frac{T_{frame} - T_{cp}}{T_{frame}}}_{CP\_loss} \cdot \underbrace{\frac{N_{sc} \cdot N_s / 2 - 4}{N_{sc} \cdot N_s / 2}}_{reference\_symbol\_loss} \quad (3)$$

where: T_{frame} is the fixed frame duration equal to 10 ms and Tcp is the total CP (Cyclic Prefixes) time of all OFDM symbols within one frame. In Figure 3, the throughput curves are plotted for every CQI value. Here, HARQ is switched off and no retransmissions are performed. The SNR gap from the achievable capacity is around 2 dB for most of the CQI values. The distance from the capacity curve is increasing with increasing CQI value which is explained by the non-Gaussian QAM (Quadrature Amplitude Modulation) constellations. The throughput with AMC is depicted in Figure 4 for one user that obtains all the available resources. This user reports the actual CQI obtained by mapping the measured SNR according to Figure 2. Note that the performance in Figures 3 and 4 looks very similar, although a maximum number of three retransmissions is allowed for the simulation in Figure 4.

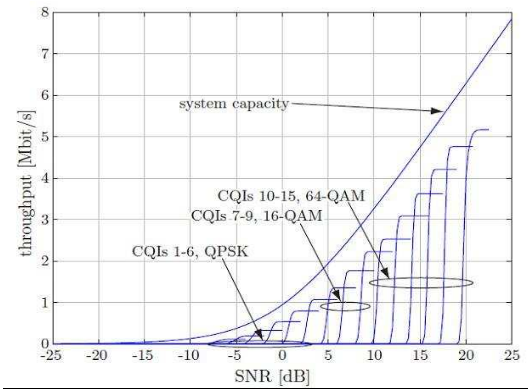

Figure 3. Throughput performance over an AWGN channel for individual CQIs without HARQ.

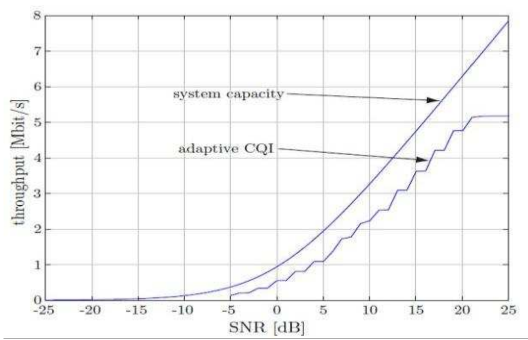

Figure 4. Throughput performance with AMC and HARQ over an AWGN chan

MIMO Throughput Results

In Figure 5, the data throughput of SISO, $2x1$ TxD (Transmit Diversity), $4x2$ TxD, and $4x2$ OLSM (Open Loop Spatial Multiplexing) is compared when transmitting over an uncorrelated ITU () Pedestrian B channel. In this simulation we set the CQI to a fixed value of seven and the maximum number of HARQ retransmissions to three. The maximum throughput values achieved by the different MIMO schemes in Figure 5 depends (1) on the number of transmit antennas and (2) on the number of data streams (layers). In the case of OLSM, two spatially separated data streams are transmitted thus leading to twice the maximum throughput of the $4x2$ TxD system. Note that the results in Figure 5 were obtained without channel adaptive precoding. An additional gain of the TxD schemes can therefore be expected when the PCI is utilized.

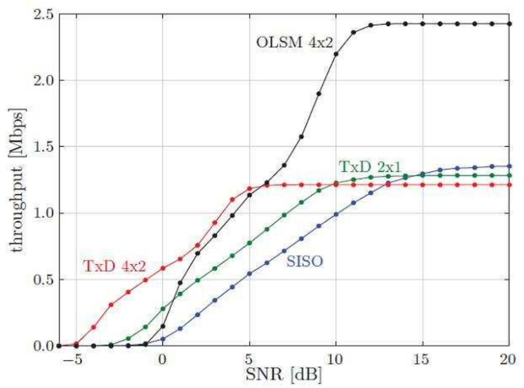

Figure 5. Throughput performance of the Open Loop Spatial Multiplexing (OLSM), the Transmit Diversity (TxD), the Transmit Diversity, and the SISO system over an uncorrelated ITU Pedestrian B channel (CQI 7, 3 HARQ retransmissions).

CONCLUSIONS

3GPP has defined the LTE technology as a means to increase mobile network performance,
provide an efficient air interface, and evolve to an all IP-based network architecture. The eNode B is a critical network element of LTE, and is responsible for control of the radio interface with the UE as well as bearer setup between the UE and EPC (Evolved Packet Core). The eNode B plays a central role in LTE UE mobility, including intra-eNode B handover, inter-eNode B handover, and inter-RAT (Radio Access Technologies) handover. The concentration of E-UTRAN (Evolved-Universal Terrestrial Radio Access Network) functionality into the eNode B calls for a wraparound testing that coordinates control and user plane activity on both radio and network interfaces.

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