Physical Layer Performance of Long Term Evolution Cellular Technology

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Abstract— **Despite commercial 3G networks are starting to be fully operational and High Speed Data Packet Access (HSDPA) is on its way to be deployed, operators and manufacturers are already in a race towards 4G technologies. The road to 4G has a mandatory milestone in Long Term Evolution (LTE) as it is a promising technology which will allow backwards compatibility besides a higher performance. Thus operators, manufacturers and research institutes are cooperating in the definition of LTE specifications. This paper presents a performance evaluation of LTE downlink physical layer according to the latest 3GPP specifications. Particularly, the main features at the LTE physical layer (like spatial multiplexing or adaptive modulation and coding) are described and analyzed.**

Index Terms— **Adaptive Modulation and Coding, Long Term Evolution, MIMO, OFDMA, LTE System Emulator.**

I. Introduction

With Radio Access Network (RAN) Evolution Workshop of November 2004 in Toronto, Canada, the Third Generation Partnership Project (3GPP) started working on the evolution of the 3G Mobile Systems. Operators, manufacturers and research institutes work together in a collaborative process to discuss views and proposals on the evolution of the Universal Terrestrial Radio Access Network (UTRAN).

Study and development on the UTRAN Long Term Evolution (LTE) is an ongoing task to develop a framework for the evolution of the 3GPP radio-access technology towards a high-data-rate, low-latency and packet-optimized radio-access technology [1]. This technology will provide a wireless broadband Internet access with advanced data services built on top.

Important changes have been required at the physical layer in order to achieve above requirements, e.g. new modulation and coding schemes, reduced Transmission Time Interval (TTI) or advanced medium access techniques. The use of Orthogonal Frequency Division Multiple Access (OFDMA), together with multi-antenna techniques allow to improve the spectral efficiency in the downlink direction.

This paper analyzes the performance of the LTE physical layer in the downlink direction. The main features introduced in the new 3GPP-LTE specifications are described and evaluated by means of simulations.

The rest of the paper is structured as follows. In Section II a brief description of LTE downlink physical (PHY) layer is presented. Obtained results are presented in Section III. Finally, Section IV gathers the main conclusions and future work.

II. LTE Downlink Physical Layer

Along this section, a brief description of main LTE downlink functionalities located at the physical layer is presented.

A. Multiple Access

Data transmission in downlink is based on OFDMA, which is a promising technique to provide an efficient access over high-speed wireless networks. Besides, it is suitable for broadcasting even in Multiple-Input Multiple-Output (MIMO) scenarios.

OFDMA achieves high spectral efficiency in multiuser environments by dividing the total available bandwidth into narrow sub-bands to be shared by users in an efficient manner. Different bandwidths are supported (from 1.25 to 20 MHz) keeping subcarrier spacing unchanged and, as a consequence, the number of subcarriers varies accordingly. This technology will offer broadband wireless access at data rates of multiple Mbit/s to the end-user and within a range of several kilometers.

OFDMA at the physical layer, in combination with a Medium Access Control (MAC) layer, provides an optimized resource allocation and Quality of Service (QoS) support for different types of services.

B. Frame Structure

Data transmission through the radio interface is organized into radio frames, with two possible structures [2]:

1) Generic frame structure

Each radio frame is 10 ms long and consists of 20 slots of length $T_{Slot} = 0.5\ ms$, numbered from 0 to 19. A subframe is defined as two consecutive slots where subframe i consists of slots $2i$ and $2i+1$. For FDD, all the subframes are available for downlink and uplink transmission in each 10 ms interval,

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where uplink and downlink transmissions are separated in the frequency domain. For TDD, a subframe is either allocated to downlink or uplink transmission. The first subframe in a radio frame is always allocated for downlink transmission.

2) Alternative frame structure (TDD only)

In this case, each radio frame consists of two identical half-frames of length $T_{Slot} = 5\ ms$ each. Each half-frame consists of seven slots, numbered from 0 to 6, and three special fields, one of them a Guard period (*Gp*). Slot #0 and another of these special blocks (*DwPTS*) are always reserved for downlink transmission, whereas slot #1 and the last special block (*UpPTS*) are always reserved for uplink transmission.

C. Slot structure and physical resource elements

Transmitted signal in each slot is described by a resource grid of N subcarriers and M OFDM symbols. The value of N varies in the range $72 \leq N \leq 2048$ (DC subcarrier not included) and depends on the transmission bandwidth. The number M of OFDM symbols per slot depends on the subcarrier spacing Δf and the cyclic prefix length (see Table I).

TABLE I
NUMBER OF OFDM SYMBOLS PER SLOT.

Configuration		**Generic**	**Alternative**
Cyclic prefix	Δf (kHz)		
Normal	15	7	9
Extended	15	6	8
	7.5	3	4

First symbol in each slot is used for transmitting control signaling. Pilot carriers (for estimation purposes) are located in the first symbol and in the third symbol from the end of the slot.

A physical resource block (PRB) is defined as M consecutive OFDM symbols in the time domain and $N = 12$ consecutive subcarriers in the frequency domain, as shown in Fig. 1.

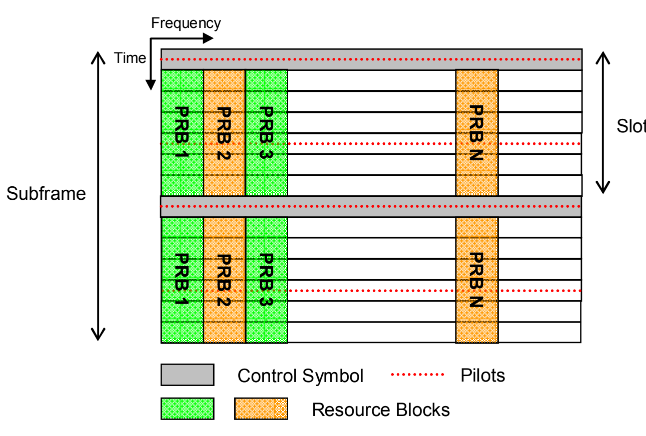

Fig. 1 Generic Subframe Structure.

D. Adaptive Modulation and Coding

Adaptive modulation technique allows to maintain the Bit Error Rate (BER) below a predefined target value by modifying the signal transmitted to a particular user according to the instantaneous received signal quality.

Additionally, the coding scheme may be also modified along the time to match the instantaneous channel conditions for each user, then being denoted as Adaptive Modulation and Coding (AMC). In this case, both modulation and coding scheme are jointly changed by the transmitter to adapt the transmitted signal to the varying channel conditions (in time and frequency domains).

Channel coding is based on Turbo Codes, with enhanced interleaving compared to HSDPA. These codes, first proposed in 1993 [3], enable reliable communications with efficiencies close to the theoretical limit predicted by Shannon [4]. Since their introduction, turbo codes have been proposed for low-power applications (e.g. satellite communications) and for interference limited applications (e.g. third generation cellular). Coding rate has been decided to be approximately 1/3 [5], i.e. for each data burst of K bits, $3K + 12$ coded bits are generated. Last 12 bits correspond to the Trellis termination. Issues as interleaving, puncturing and rate matching are currently under discussion in 3GPP-LTE Working Groups. On the other hand, control information is decided to be convolutionally coded with a coding rate of 1/2.

E. MIMO

Multi-antenna techniques have been integrated as part of the long-term 3G evolution. Requirements on coverage, capacity and data rates make necessary to incorporate new transmission schemes, such as beamforming or spatial multiplexing (commonly referred to as Multiple Input Multiple Output or MIMO). Transmit diversity can be used to improve coverage and capacity, and Spatial Division Multiplexing (SDM) increases data rates by transmitting multiple streams to a single user.

The baseline antenna configuration consists of two transmit antennas at the base station and two receive antennas at the Mobile Terminal (MT). The possibilities for higher-order schemes are considered up to a maximum of four transmit and four receive antennas [6]. Modes of operation for unicast traffic are: spatial multiplexing, beamforming, and single-stream transmit diversity. The MIMO mode is restricted by the MT capability, and is determined according to the slow channel variation. This adaptation requires additional control signaling and should be performed slowly (e.g. every several 100 msec) in order to reduce overhead.

Recent discussions within 3GPP meetings agreed on the use of transmit diversity for control channels, while SDM will be considered for transmitting user data under good channel conditions. A concrete solution for transmit diversity mode is not defined yet. Possible candidates are block-code based transmit diversity, time (or frequency) switched transmit diversity and cyclic delay diversity.

Multiplexing of different symbol streams for different MTs using the same time-frequency resource is supported as well, being denoted as Spatial Division Multiple Access (SDMA) or multi-user (MU)-MIMO. Adaptive modulation and coding rate are applied independently for each stream in order to track fast channel variations within a control interval between 0.5 and a few ms.

Some of these multi-antenna schemes, such as SDMA, are very sensitive to ill-conditioning of the channel matrix. To solve this problem, the use of precoding techniques is being taken into account. The 3GPP outgoing discussions will be focused on the particular implementation of these schemes, considering the tradeoff between the receiver complexity requirements and the performance of the MIMO algorithms.

III. Performance Evaluation

A. Simulation Environment

The downlink direction of a LTE wireless system has been evaluated in this section. The scenario under analysis is compound by a set of Mobile Terminals (MT) connected to a Base Station (BS) or E-NodeB through a frequency-selective radio channel (see Fig. 2).

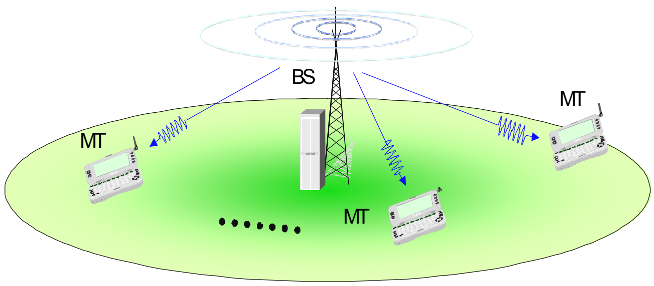

Fig. 2. Scenario under analysis.

Simulations have been run over an LTE downlink emulator built on WM-SIM platform [7]. Simulation parameters are summarized in Table II.

TABLE II
SIMULATION PARAMETERS

Parameter	Value
Carrier Frequency (f_c)	1.8 GHz
Sampling Frequency (f_s)	30.72 MHz
Channel type	Flat Rayleigh
Mobile terminal speed (v)	≈11 m/s
Cyclic prefix length	144 samples
Bandwidth	20 MHz
Number of data carriers	1200
FFT size	2048
Coding Rate	1/3
Feedback Delay	1 subframe

B. Adaptive Modulation

Adaptive modulation technique is based on the modification of the transmission rate according to instantaneous received SNR in order to maintain instantaneous BER below a predefined target value (BER_T). An ideal feedback channel of 1 subframe delay has been assumed for reporting the Channel Quality Indicator (CQI) from the receiver to the transmitter. This indicator is calculated in each MT on a subframe basis.

For a given BER_T, several SNR thresholds are defined to decide which modulation scheme will be used for an instantaneous SNR value. For very low SNR values, the transmission may be suspended for a particular MT (outage) until its channel conditions improve. The existence of outage periods implies a reduction of system efficiency.

In Fig. 3, the average BER results for different BER_T values are shown. Even for low average SNR values, average BER keep always below the chosen target value.

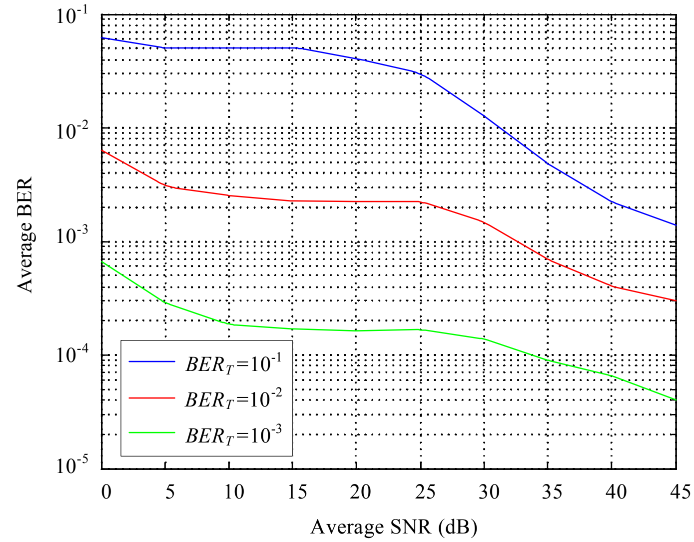

Fig. 3. Average BER vs. Average SNR for different BER_T

C. Scheduling

As in HSDPA, scheduling in LTE is moved to E-NodeB due to the even shorter TTI (2 ms for HSDPA versus 1 ms for LTE). Election of a suitable scheduling algorithm is the key to reach a good service performance. Decision criteria vary from algorithm to algorithm being channel quality the most referred. Besides, it is also possible to implement Quality of Service (QoS) policies offering different services to distinct users.

Two different scheduling algorithms (*Round Robin* and *Best Channel*) have been evaluated.

1) Round Robin

Round Robin (RR) is a simple scheduling algorithm in which transmission turns in a specific bandwidth are assigned to different users in a cyclic way. All users are handled without priority and, therefore, there is no discrimination among users, i.e. it is starvation-free.

Although it is the simplest scheduling algorithm, it is fair in the way resources are allocated among users when the mean rate for each data flow is similar. However, this algorithm is inefficient over fading channels since it does not take into account channel state information. Therefore, a lower system throughput is expected.

2) Best Channel

When *Best Channel* (BC) algorithm is used, those users with the best channel conditions are prioritized; therefore this algorithm maximizes the system efficiency. However, it has an obvious drawback as it lacks of fairness in the way resources are allocated to users. Users with bad channel conditions are ignored, and consequently, their experienced delay increases.

Delays for different MTs are shown in Fig. 4 both for RR (solid line) and BC (dashed line) multiplexing algorithms. Average SNR values for different users have been computed as a lognormal distribution with mean 20dB and 3dB deviation. This figure makes clear how BC algorithm is very sensitive to SNR, and therefore, delays for different MTs depend on their channel conditions (MTs with worse channel have larger delays).

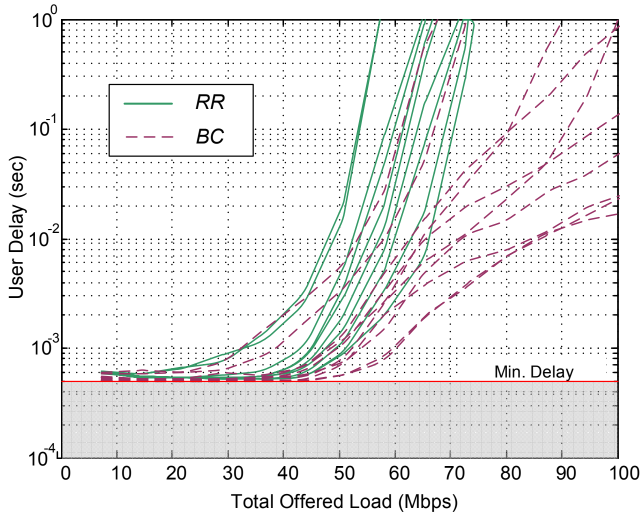

Fig. 4. Delay evolution versus Normalized offered load for 5 MTs.

D. Channel Coding

Turbo encoder at the transmitter is implemented according [5]. It is made up by two twin systematic encoders that independently encode an input data burst. In order to obtain a different result from each encoder, an interleaving is added before one of the encoders to de-correlate their output bits.

Decoding functionality in the MT is based on the use of a twin Viterbi decoder in such a way that output information from the first decoder is used as input for the second one to make a better decision. This process could iterate several times in order to improve results. However, the number of iterations in decoding process has been limited to k = 2 in order to reduce computational cost.

Both for 16 QAM and 64QAM (highest modulations proposed for data in LTE) there is approximately a coding gain of 6 dB in BER values despite the low number of iterations (see Fig 5).

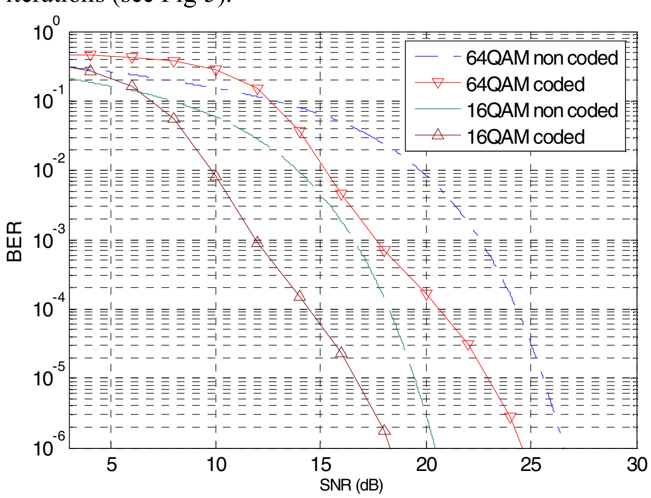

Fig. 5. BER results with and without coding for 16 QAM and 64 QAM.

This figure shows how even with a low number of iterations (k =2), BER values are improved when coding is used.

It must not be neglected that proposed coding rate is quite high (close to 1/3) and, therefore, lot of redundancy is added to original data flow. This coding rate is used as "mother code rate" and it will change when rate matching process is defined. Puncturing and rate matching will be added as soon as they are defined in [5]. Besides, Implementation and evaluation of both maximum a posteriori (MAP) based decoding algorithms (based on [8]) and Soft Output Viterbi Algorithm SOVA [9] is an ongoing task.

E. MIMO

As stated in section II, several multi-antenna transmission schemes have been proposed for the LTE physical layer. Although concrete implementations have not been defined yet, the use of spatial division multiplexing in order to improve capacity is already approved. This way, a basic SDM scheme with two transmit and two receive antennas is a first approach towards other more complex candidate scenarios.

The implemented scheme consists of multiplexing consecutive slots through two transmit antennas. Signal detection at the receiver is based on zero-forcing algorithm. Precoding techniques are not included at the moment, being a pending issue for evaluation. Fig 6 depicts the spectral efficiency improvement when applying SDM with respect to the Single Input - Single Output (SISO) transmission.

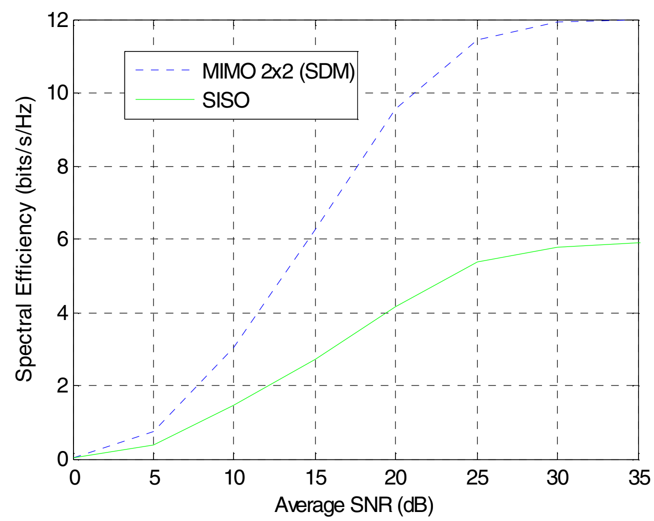

Fig. 6. Spectral Efficiency for SISO and MIMO 2x2 with spatial division multiplexing scheme

F. System Performance

This section analyzes the impact of system load on the user throughput under a SISO scenario. The simulation assumes an increasing number of users in the system (from 1 to 40) generating a mean source rate of 3.85 Mbps each. Figure 7 shows how for low values of total offered load, what means few terminals in the cell, effective throughput for a particular MT is almost constant and close to the source rate. However, when total offered load is close to system's capacity (≈ 60 Mbps), effective throughput declines gradually.

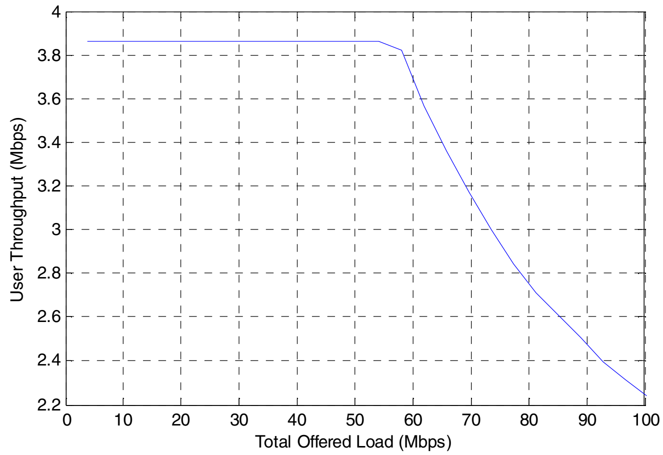

Fig. 7. User Effective Throughput versus Total Offered Load in the system.

IV. CONCLUSIONS

This paper has analyzed the performance of the new LTE cellular technology. The analysis has focused on the main features involved in the downlink, like the user multiplexing, adaptive modulation and coding, and support for multiple antennas.

Adaptive modulation and coding feature has been validated as an efficient and reliable transmission technique to maximize the spectral efficiency while fulfilling the BER requirements. Simulation results show a maximum LTE capacity around 60 Mbps (for 20MHz system bandwidth), which may be even duplicated when 2x2 antenna configuration is applied.

Future work is aimed to perform the complete LTE physical layer analysis, including the uplink scenario and focusing on the ongoing changes in the LTE specification process.

ACKNOWLEDGMENTS

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