Simulating the Long Term Evolution (LTE) Downlink Physical Layer

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Abstract— **In this paper we investigate a comprehensive analysis of Long Term Evolution Advanced (LTE) downlink (DL) physical layer performance using Multi Input Multi Output channel (MIMO) based on standard parameters. The work consists firstly in modeling LTE physical downlink shared channel (PDSCH). The developed model is based on an independent functional blocks in order to facilitate reproduction of signal processing techniques results used in LTE and particularly to evaluate the physical layer downlink components. Thereafter, it was integrated in the simulator, basic structure with AWGN channel including evaluation of using diversity and spatial multiplexing transmissions on downlink connections and multipath fading channel model. The simulation examples are illustrated with different digital modulation and MIMO scheme. BER and throughput results with multipath impact on transmission channel quality are also considered. These results show that the model implemented in Matlab faithfully advantages introduced in the LTE system.**

Keywords- Long-term evolution (LTE); Downlink Physical-layer; Simulation; Multi Input multi Output (MIMO); Orthogonal frequency division multiple access (OFDMA)

I. INTRODUCTION

In Release 8, LTE system [1, 2] was standardized by 3GPP as the successor of Universal Mobile Telecommunication System (UMTS). Its progression continues to LTE-Advanced release-12 [3] in order to increase data throughput and efficiency spectrum, representing an evolution of previous technologies: UMTS, HSPA, and HSPA+. The LTE radio interface proven previously [4], has been optimized for mobile networks. LTE has several other benefits, particularly high throughput as well as reducing latency [5]. The LTE downlink transmission scheme is based on Orthogonal Frequency Division Multiple Access (OFDMA) where the wide-band frequency selective channel is converted in many fading sub-channels [6]. This method allows the system to operate in channel bandwidths from 1.4 MHz to 20 MHz. This flexible band and a very finely divided carrier, offer LTE to achieve significantly higher speeds (> 1Gbit /s for downlink) than its predecessors. It allows adaptive radio settings to channel, through intelligent use of bandwidth and resources like adaptive modulation, coding and MIMO technology [7]. Realistic LTE standard performance evaluation requires well-adapted simulators. Several simulators have been developed [8, 9], some of them [10, 11] assess the LTE network layer. Our goal in this work consists to facilitate the understanding and evaluating of physical layer various aspects. It can also assists engineers in manipulating mathematical LTE bricks in order to go from specification to implementation. Matlab simplifies specification for ease of configuration and addition of specific algorithms (where the standard permits) and generates languages like C or VHDL which can implemented on eNodeB or UE and will upgrade the equipment on this standard.

The paper is organized as follows: in section II, a simulator structure detailed description is performed, integrating all physical downlink shared channel PDSCH functional blocks. Simulation results are illustrated and discussed in section III and a conclusion is done in section IV.

II. SIMULATOR STRUCTURE

The LTE simulator consists on functional blocks within physical downlink shared channel PDSCH [12,13] from transmitter (eNodeB) to receiver (UE). The PDSCH carries data in Transport Blocks (TB) and they are passed from MAC layer to physical layer once per Transmission Time Interval (TTI). Physical resources are assigned by two resource blocks for one TTI. The simulator description structure consists on downlink transmission and receiver chain diagram where each block will be described.

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A. *Transmission scheme*

In this subsection we describe all functional blocks within downlink transmission chain diagram (see Figure 1).

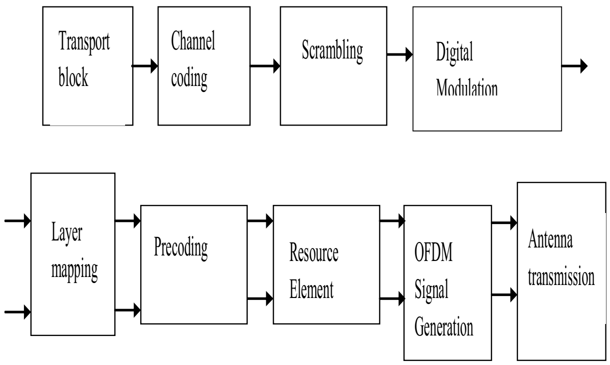


Figure 1. Functional blocks within downlink transmission chain Diagram

Channel coding: a Cyclic Redundancy Check (CRC) [14] is used and appended to each user's TB.

Scrambling: Each code word transmitted to physical channel in a sub-frame must be scrambled by a calculated scrambling sequence before modulation to encounter with intercellular interference.

Modulation: complex symbols modulated according to possible modulations for DL-SCH (QPSK, 16-QAM, 64-QAM).

Antenna mapping: mapping layer and pre-coding: Complex symbols are mapped to one, two or four antennas and they will be treated differently. In single antenna port situation, a single layer is used, this antenna mapping depends on the Rank Indicator (RI) feedback [15]. In mapping layer block, a precoding block generates a sequence for each antenna port. Three types of PDSCH pre-coding are available [16, 17]: spatial multiplexing, transmit diversity (TxD), and transmission to single antenna port. A precoding, an Open Loop Spatial Multiplexing (OLSM), and without precoding a Closed Loop Spatial Multiplexing (CLSM).

Generating OFDM signals: to create OFDMA signal transmitted on each antenna requires mapping symbols to different OFDM signal subcarriers and adding Cyclic Prefix (CP) to avoid inter-symbol interference and the reference symbols for channel estimation.

Resource mapping and resource grid/resource element: The transmitted signal in each slot is described by a time-frequency resource grid composed with resource element of one subcarrier OFDM symbols during one OFDM symbol.

Channel Model: The propagation channel distorts the transmitted signal and also includes noise, this in agreement with the model selected channels. There are many LTE channel models also known as frequency-selective channels modeled by ITU [18] and 3GPP [19]. In this work we involve AWGN integration into LTE link level simulator also including pedestrian, vehicle and typical urban cases as in [20].

B. *Receiver structure*

The receiver (UE) structure is described in figure 2. Each UE receives the signal transmitted by eNodeB and performs transmitter reverse physical-layer processing. Inverse OFDM mapping is applied to the received signals. The UE needs to estimate the channel so information generated will be supplied to the equalizer and also to the Matrix Pre-coding Indicator (MPI) calculator [21, 22]. After layer mapping extraction, two treatments lines operate in parallel. For each TTI, demodulation, reverse flow adaptation and channel decoding are successively performed. Finally, the MPI is feedback to eNodeB and decoded bits will be transferred to computation block output to evaluate transmission performance.

Channel estimation*:* Signal reference symbols are inserted with fixed subcarriers per antenna port. Thus, the preliminary step is to estimate channel reference signals "frequency subcarrier" in frequency domain and sub-frame in time domain. The main feature of this unit (implemented only in CLSM) is to provide an estimated channel to the equalizer and to generate MPI [22]. Based on this (channel estimation), channel quality may be evaluated and the appropriate feedback information calculated. After channel estimation, interpolation is applied to other symbols in frequency-time domain [23].

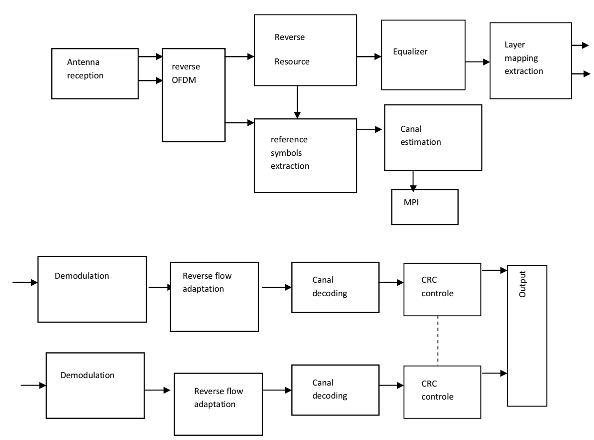


Figure 2. LTE receiver diagram

Equalization: The equalizer performance depends on channel estimation and is used to reduce inter-symbol interference (ISI) due to channel frequency selectivity and also to recover original signal. The equalizer is composed of two blocks: one consists on a Linear Minimum Mean-SquarError receiver (LMMSE) [23] for both single transmitting antenna and spatial multiplexing. The second block concerns spatial diversity, which consists on a decoding algorithm for each receiving antenna, followed by a decoded values combination for all receiving antennas.

Reverse flow adaptation during demodulation: channel knowledge is also used for OFDM signal demodulation and soft de-mapping. Segmenting and swapping demodulator output, data were reconstructed in code-words that will be sent to turbo decoder. The reverse flow adaptation includes segmentation, padding with zeros and de-interleaving sub-block.

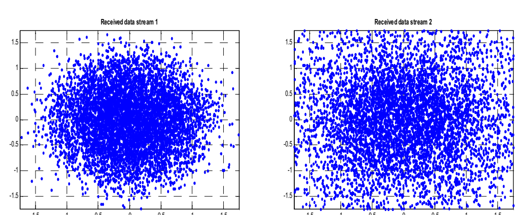
Channel decoding: The turbo decoder is composed by two weighted elementary and serial input/output decoders which work sequentially in an iterative turbo decoding process. After a sufficient iterations number, the decoded sequence is available at the second decoder output after de-interleaving. At every turbo iteration a CRC check [14] of decoded block is performed. After each evaluation, receiver provides information to evaluate throughput and Bit Error Ratio (BER).We note that methods for feedback calculating and HARQ are missing.

III. LTE PHYSICAL LAYER PERFORMANCE

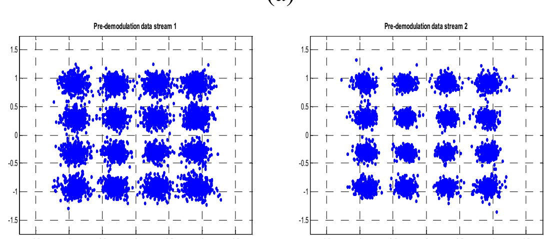
The simulator is highly configurable and flexible and can adapt to various situations (inner city, suburbs, country) and various mobility conditions (stationary/mobile) modeled by Rayleigh channel Bandwidth 1.4 to 20 MHz. The channel model follows EPA-LTE, a pedestrian channel model for LTE system [20]. The simulator parameters were adjusted to LTE downlink transmission: an ideal AWGN channel and a MIMO-scheme with CLSM, based on a pre-coding dictionary using a physical channel terminal category V [22]. The turbo encoder rate is 1/3, whenever Turbo Code is used; CP type is extended and 8 iterations at the turbo decoder.

A. Digital modulation technique

We visualize channel equalization effects for 16-QAM symbols constellation received symbols in downlink transmission with SNR= 20 dB, before equalization (Figure 3a) and after equalization (Figure 3b).



(a)



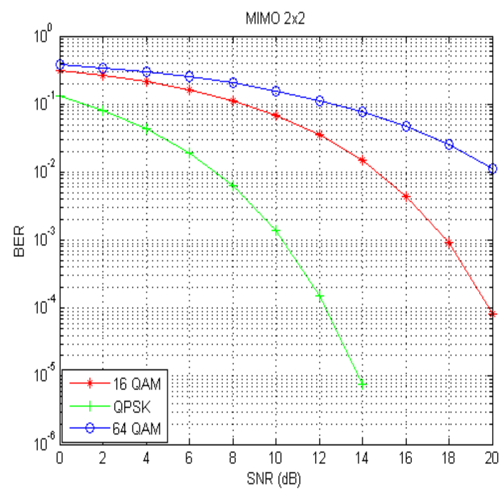
(b)

Figure 3. Received symbols: (a) before equalization (b) after equalization

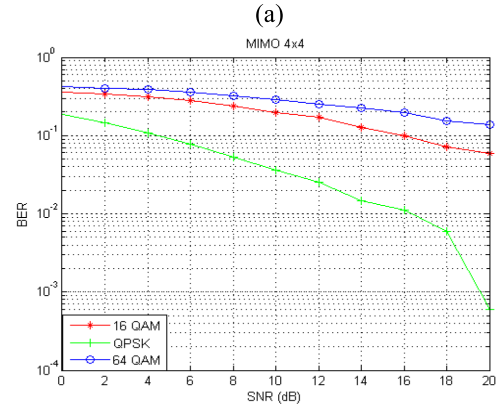
B. BER results

BER performance is compared using spatial multiplexing with different digital modulation. Figure 4(a) illustrates the transmission gain with MIMO 2x2, whereas Figure 4(b) depicts the results with MIMO 4x4.

We can observe that a good BER is obtained with QPSK modulation compared to 64 QAM and MIMO 4x4 causes a stronger degradation in terms of BER performance, as expected (in spatial multiplexing several information are transmitted through multiple antennas simultaneously). We can also observe that if transmit antennas number grows, the SNR required to achieve a given BER decreases.



(a)



(b)

Figure 4. BER versus SNR (dB): (a) MIMO 2x2 (b) MIMO 4x4

C. MIMO throughput results

In this subsection, throughput performance over an AWGN channel is compared for two MIMO schemes (see figure 5).

If more transmit antennas are utilized, more pilot symbols are inserted in the OFDMA frame and thus lower maximum throughput can be achieved. In the case of two OLSM spatially separated data streams are transmitted thus leading to twice the maximum throughput. Note that for all three types of modulations flow increases in a linear manner with the MIMO system. In MIMO 2x2, the maximum throughput is close to 80 Mb/s for 64-QAM modulation. Indeed, it was previously shown whenever the constellation increases, the flow is better. We also note that the effect of bandwidth is crucial

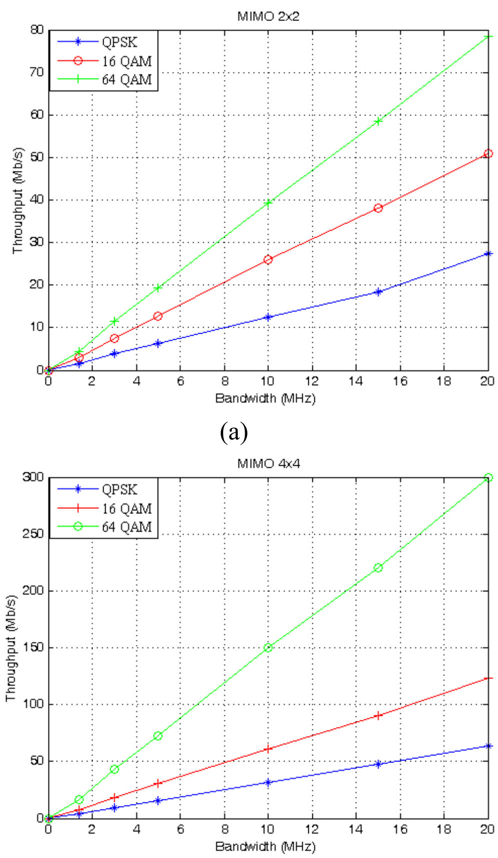


Figure 5. System capacity over an AWGN channel with: (a) MIMO 2x2 ; (b) MIMO 4x4

D. Channel model: Multipath Fading Propagation

In addition to multipath delay profile, a maximum Doppler frequency is specified for each multipath fading propagation condition. A Doppler shifts is integrated that arise from relative motion between transmitter and receiver which specifies three different delay profiles which are representative of low, medium and high delay spread environment. These are EPA (Extended Pedestrian A Model), EVA (Extended Vehicular A Model) and ETU (Extended Typical Urban Model A).

In Figure 6, BER performance is compared for two scenarios (EPA) and EVA with maximum Doppler frequency 5 Hz and 70 Hz, and MIMO 2x2 for 3 modulations: respectively Fig. 6a for 64QAM, Fig. 6b for 16QAM, and Fig. 6c for QPSK

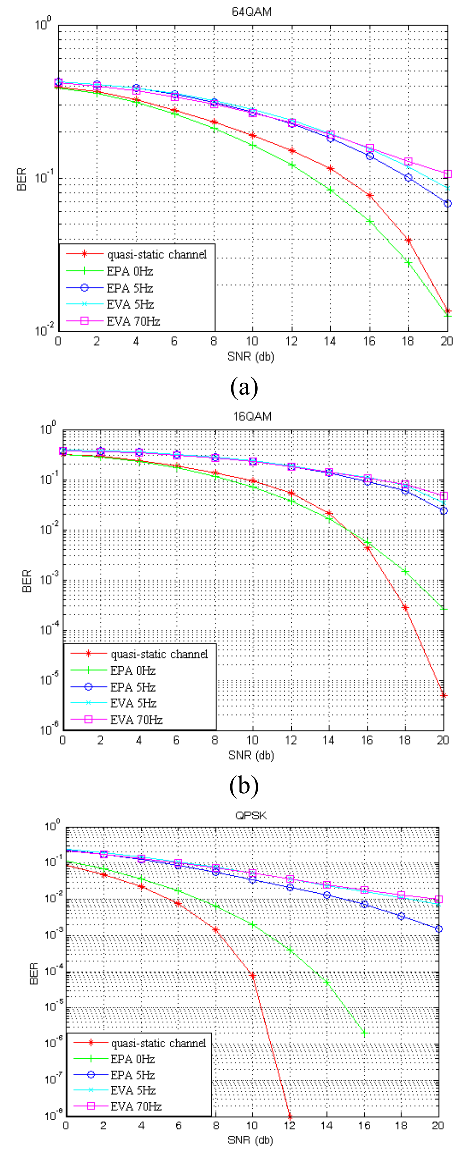


Figure 6. Downlink transmission spatial multiplexing: (a) 64 QAM (b) 16 QAM (c) QPSK

One can observe that 64 QAM scenario causes a stronger degradation of BER performance, as expected. Moreover, BER performance using EVA is almost the same as in the case where EPA= 5 Hz with a bandwidth less than 14 MHz. In Figure 6(c), we observe that whenever Doppler frequency increases, we get a higher BER. Indeed, the signal doesn’t suffer from deviation from EPA and EVA modes, for new paths that generate more errors. With a favorable channel, we can afford to use high modulation rates less sensitive to channel conditions (M-QAM), and allow more users to communicate without degrading the QoS.

Inversely, if the channel is severe, a more robust modulation is used like QPSK, it takes advantage on carrier orthogonality, but BER is reduced. Upon receiving a signal which has undergone the multi path was the same copy arriving but time-shifted. To address this, it is necessary that cyclic prefix length is longer than delay spread duration. So the last echoes of first OFDM symbol will take place during the cyclic prefix and next OFDM symbol will not be disturbed.

IV. CONCLUSION

In this paper, a physical layer simulation of LTE system has been modeled and presented in the simplest possible way to better understand physical layer downlink LTE technology general operation. Through simulations, we highlight the LTE system performance. It is clear that antennas number and bandwidth choice are key factors in achieving theoretical speeds advertised with a wide selection MIMO and adequate bandwidth. The multipath fading propagation channel models was also considered and we can verify that multipath channel impact on transmission quality. Mobility creates delay which directly influences traffic between eNodeB and UE, causing packet loss and a drop in speed. With LTE system using MIMO and OFDMA due to cyclic prefix allows overcome these problems.

Mobile radio technologies have continued and will continue to evolve to meet the requirements of multimedia applications and quality of service in the near future will give birth to 5G.

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