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***Abstract*—3GPP LTE is the evolution of UMTS which will make possible to deliver next generation high quality multimedia services according to the users' expectations. The flexibility of the downlink OFDM radio interface with Adaptive Modulation and Coding (AMC), MIMO and H-ARQ plays a crucial role in achieving the low latency and high spectral efficiency promised by the new radio access standard. This paper presents a LTE DL link level simulator whose main purpose is to generate suitable look-up tables to interface with a system level simulator. In this context, the Exponential Effective SIR (EESIR) metric is a link abstraction model that is used to properly characterize multistate channels. The reference BLER curves in AWGN channel and the parameters of the EESIR model are given for the complete list of CQI's specified for LTE DL. The obtained results also include curves of mean link level throughput for different AMC formats and MIMO configurations**

I. INTRODUCTION

3GPP LTE is the evolution of UMTS which will make possible to deliver next generation high quality multimedia services according to the users' expectations [1]. OFDM/OFDMA have been selected by 3GPP as the physical layer and multiple access schemes for DL LTE. OFDM can deliver a high bit rate even in a heavy multipath environment thanks to the use of many narrow-band subcarriers which are easy to equalize. Furthermore, since fading is almost flat within each subcarrier, suitable MIMO schemes can easily be applied on a subcarrier basis. OFDM shows an inherent frequency diversity effect if a coded block is sent on a set of subcarriers spanning a bandwidth higher that the channel coherence bandwidth. Adaptive modulation and coding (AMC) allows delivering a reasonable throughput to the users at the cell border while achieving high spectral efficiency for users near the eNB. Another key aspect of the LTE DL radio interface is the use of fast retransmission at the MAC level with incremental redundancy (H-ARQ). H-ARQ smoothes the AMC throughput curves, thus allowing less frequent switching between AMC formats.

In this paper we describe an adhoc LTE DL link level simulator, entirely written in C++, which can generate the suitable look-up tables for the EESIR model to interface with a LTE system level simulator. A methodology to train the EESIR model using the link level results is explained and the reference BLER curves in AWGN channel and the parameters of the EESIR model are given for the complete list of CQI's specified for LTE DL. Results showing mean link level throughput vs. mean SIR are given as well.

The paper is organized as follows: section II is a description of the developed simulator, section III presents the results focusing on average performance figures, section IV describes the methodology for training the EESIR model and discusses the results and section V includes the conclusions and future work.

II. DESCRIPTION OF THE E-UTRA DL LINK LEVEL SIMULATOR

In order to feed a system level simulator with the link level performance, an ad-hoc link level simulator has been programmed in C++ language. The E-UTRA DL link level simulator features an OFDM physical layer in accordance with [2] and [3], (see Fig. 1). The rate 1/3 turbo encoder with variable code block size creates three independent streams with systematic and redundant bits. Those streams are interleaved and fed to the circular buffer rate matching and H-ARQ procedure. Variable coding rate is achieved by applying different puncturing patterns depending on the current H-ARQ redundancy version (RV). Up to four incremental redundancy (IR) transmissions per code block are allowed. The turbo decoder uses a MAP algorithm and a maximum of 8 decoding iterations. ACK/NACK error free transmission is considered.

The QAM modulator generates the complex modulated symbols, belonging to either a QPSK, 16QAM or 64QAM constellation. Signalling and pilot symbols overhead is not considered. After the IFFT and the cyclic prefix (CP) addition, the time-domain samples are processed by the stochastic MIMO multipath mobile channel simulator. In SISO mode the mobile channel simulator can simulate any desired power delay profile (p.d.p.) (including Rice distributed LOS propagation path). The Doppler spectra of the different paths are shaped by a classical Jakes low-pass filter. In MIMO mode the channel simulator uses a stochastic matrix channel model that includes the antenna correlation effects. All elements of the matrix channel are independently generated as for the SISO channel according to the same p.d.p.. Correlation among antennas is introduced using the procedures recommended in [4]. Based on this assumption, the spatial correlation matrix of the MIMO radio channel is the Kronecker product of the spatial correlation matrix at the receiver and transmitter. Ref. [4] also specifies three different levels of antenna correlation, termed low, medium and high correlation level. The antenna correlation parameters from [4] have been applied to obtain the results presented in this paper.

Ideal channel estimation is assumed for channel equalisation (one tap equalizer in SISO mode) and for MIMO processing at the receiver. The simulator includes MIMO spatial multiplexing modes with linear receivers (Zero Forcing and MMSE) as well as Alamouti space frequency coding transmission diversity.

In order to speed up simulations, the link level simulator is split in two independent programs. The first stage includes the wideband OFDM modulation/demodulation and the multipath channel. The output of this stage is the set of the log-likelihood ratios (LLR) of the received encoded bits. The second stage filters the set of LLRs, which account for all the simulated OFDM subcarriers, to extract the LLRs of the Physical Resource Blocks (we consider 1 PRB = 12 subcarriers x 1ms) allocated to the simulated user. In this way the time and frequency correlations of the channel response, as seen by the mobile terminal, are properly captured. The set of LLRs are used in the second simulation stage to feed the turbo decoder with the soft reliability values of the received bits.

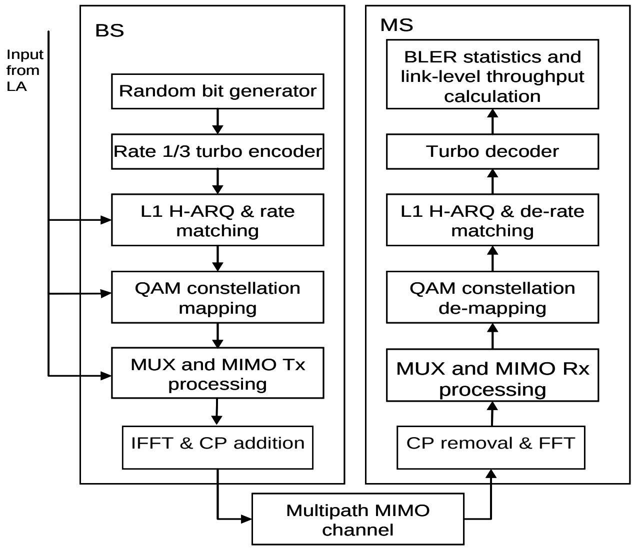

Fig. 1 Block diagram of one MIMO layer of the E-UTRA DL link level simulator

III. LTE DL LINK AVERAGE THROUGHPUT

The set of parameters used in the simulations are shown in TABLE I. In order to test the validity of the simulator results, several curves of the uncoded BER were first obtained. Fig. 2 shows the mean uncoded BER vs. mean SIR, for QPSK and 16QAM with MIMO 2x2 in spatial multiplexing mode and in Alamouti transmit/receive diversity mode. When using the Alamouti scheme, two antennas at the mobile node are used to implement an order 2 MRC receiver diversity scheme. This mode gives a BER slope corresponding to order 4 diversity. This is in contrast with the slope for an Alamouti 2x1 scheme (also shown in Fig. 2) that corresponds to order 2 diversity. Also in Fig. 2 the BER slope for the MIMO spatial multiplexing modes corresponds to a typical Rayleigh environment BER curve. MMSE receiver slightly outperforms ZF receiver. The multipath channel model considered in Fig. 2 is Extended Pedestrian A (EPA), as specified in [5], with a 3km/h pedestrian speed.

TABLE I. LINK LEVEL SIMULATOR PARAMETERS

Parameter	Value
Carrier frequency	2 GHz
Simulated Bandwidth	20 MHz
Sub-carrier spacing	15 kHz
OFDM PHY parameters	Cyclic Prefix of 4.69 μs
FFT size	2048
Number of useful sub-carriers	1200
OFDM symbol duration	71.43 μs
Number of sub-carriers per PRB	12
Number of allocated PRBs	1
TTI interval	1 ms
Number of useful OFDM symbols per TTI	11
Power Delay Profile	AWGN, EPA channel model at Pedestrian speed (3 km/h) and Extended Typical Urban (ETU) channel model [5]
Channel Coding	Turbo code basic rate 1/3
Rate Matching and H-ARQ	According to [3]. Max 4 IR transmissions.
AMC formats for training EESIR model	As specified in [8] for each of the 15 possible CQI indexes
Channel estimation	Ideal
Antenna scheme	SISO and MIMO

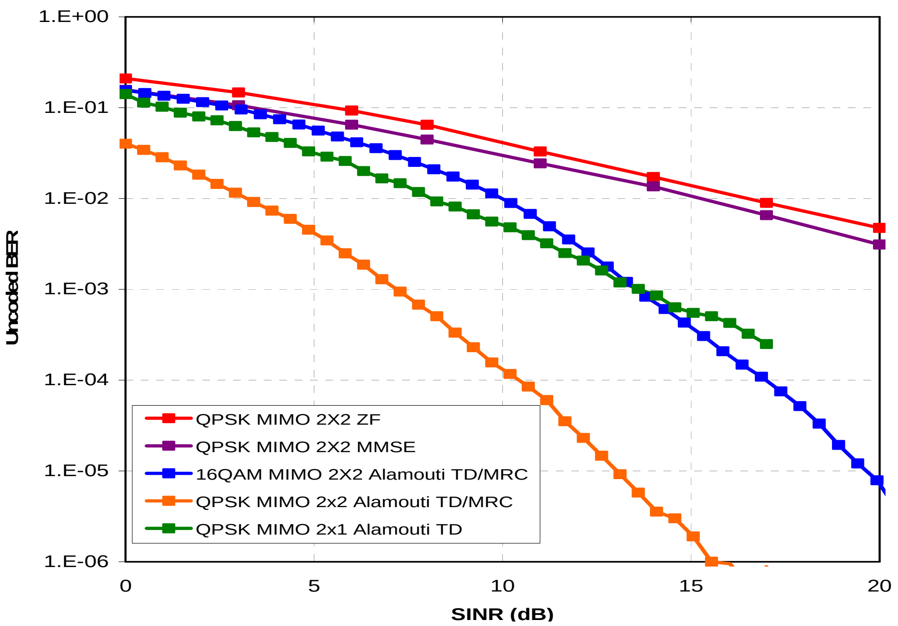

Fig. 2. Uncoded BER vs. mean SIR for different modulations and MIMO configurations in EPA multipath channel @ 3km/h

In order to obtain results on mean link level achievable throughput, the bandwidth allocated to the simulated user has been set to 1 PRB and the simulated turbo code block sizes are the smaller ones specified for E-UTRA DL (nevertheless the simulator time resolution corresponds to a 20MHz bandwidth). The obtained link level throughput can thus be considered the E-UTRA DL baseline performance, since higher code block sizes and the inherent frequency diversity of using a set of PRB's will lead to higher throughput figures. The mean throughput is evaluated as the product of the modulation spectral efficiency (in bits/s/Hz) times the code rate and the H-ARQ retransmission efficiency. The SIR is averaged over fast fading but not over shadowing fading, which is properly modelled at system level simulation.

Fig. 3 and Fig. 4 show the E-UTRA DL throughput, for different modulations and code rates, with 2x2 MIMO spatial multiplexing mode (MMSE receiver) and EPA multipath channel at a pedestrian speed of 3km/h. Each of these figures assumes a different correlation level between antennas. It can be verified that the antenna correlation has an important impact on the achievable throughput with MIMO.

Fig. 5 compares the mean throughput for Alamouti Tx/Rx diversity vs. MIMO spatial multiplexing with MMSE processing. For low correlation MIMO channel, spatial multiplexing gets higher throughput than Alamouti/MRC if average SIR is higher than 10 dB. For medium and high correlation MIMO channel the throughput obtained by Alamouti/MRC, below an average SIR of 21 dB and 27 dB respectively, is higher than the obtained by MIMO/MMSE. So, as it's usually recognized, spatial multiplexing mode makes more sense at high SIR.

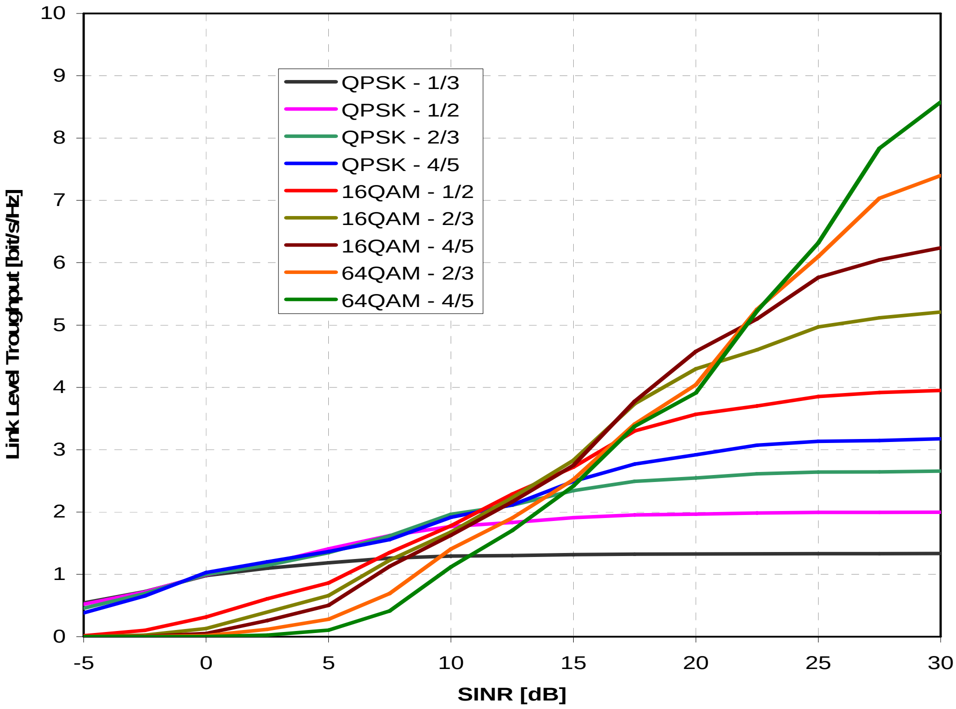

Fig. 3 E-UTRA DL 2x2 MIMO MMSE link level throughput with H-ARQ in multipath EPA channel 3km/h and medium antenna correlation

IV. TRAINING THE EESIR MODEL FOR MULTISTATE CHANNELS

The classical approach for interfacing link level to system level simulators is to generate look-up tables of mean coded BER versus the mean SIR values. This approach is no longer valid for wideband packet mode systems like LTE, where one transport block, made up of one or more code blocks, is send in a TTI of 1ms using a variable number of physical resource blocks. In LTE each physical resource block occupies 12 OFDM subcarriers (180 kHz). Due to the short duration of one TTI, with the exception of high speed vehicular environments, the wideband channel transfer function will undergo only little variations during the transmission of a single code block. Under this conditions, the BLER vs SIR curve for a given transport format (a given combination of modulation, code block size and code rate) could be approximated by the BLER curve for that transport format combination under AWGN channel conditions. An additional penalty, in the form of a noise increase, can be introduced to take into account the residual channel distortion due to imperfect channel estimation/equalization and the possible transmitter distortion (error vector magnitude). The only obstacle is that, in a wideband multipath channel environment, each OFDM subcarrier may suffer a different attenuation. The transmitted code blocks are thus affected by a multistate channel. In the literature, [6] [7] [9], the EESIR link abstraction model is introduced to account for multistate channels while still being able to use the AWGN BLER vs. SIR curve as a reference for the BLER estimation under real conditions.

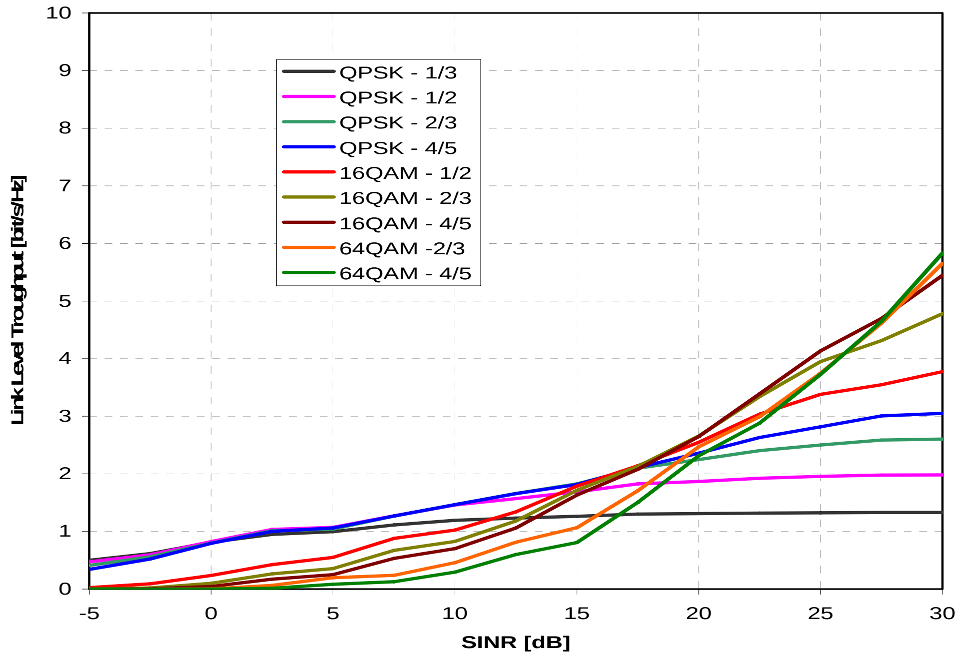

Fig. 4 E-UTRA DL 2x2 MIMO MMSE link level throughput with H-ARQ in multipath EPA channel @ 3km/h and high antenna correlation

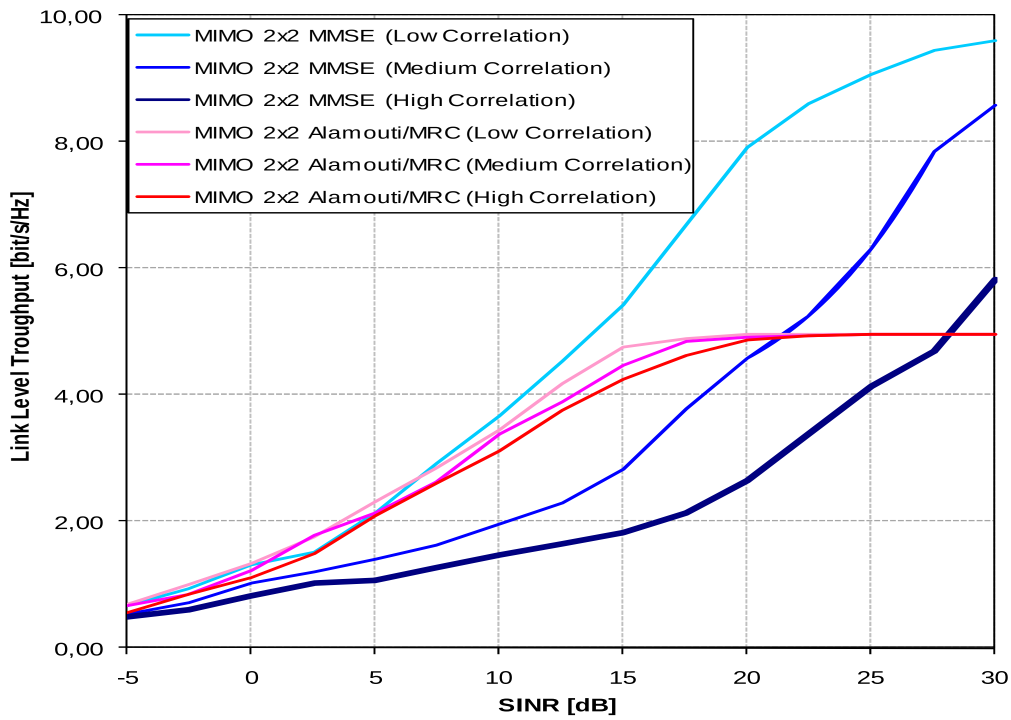

Fig. 5 E-UTRA DL Alamouti vs. spatial multiplexing link level throughput with H-ARQ in multipath EPA channel @ 3km/h

For a given multistate channel with N different SIR measurements $\{\gamma_1,\gamma_2,\ldots,\gamma_N\}$, the EESIR is defined as the value, γ_{ef}, that accomplishes the equation, [9]:

$$\gamma_{ef} = -\beta \ln\left(\frac{1}{N}\sum_{k=1}^{N} e^{-\frac{\gamma_k}{\beta}}\right) \tag{1}$$

where N depends on the frequency resolution of the measurements available at the mobile node. At the mobile node, knowledge of the EESIR metric for each resource block group (RBG) is required in order to report the CQIs specified by LTE, so in practice the value of N should span a bandwidth equivalent to one RBG. A RBG is a set of 1, 2, 3 or 4 consecutive resource blocks (the actual value depends on the system bandwidth, see [8]). The parameter β allows adjusting the experimental BLER measurements to the reference AWGN BLER curve. Once β is known the reference curve can be used to obtain an estimation of the BLER under any multistate channel for which a set of measurements is available. By using eq. (1), the EESIR concept summarizes all these measurements in a single scalar value. The value of β, specific for a given modulation, multi-antenna/diversity configuration, code block size and code rate, must be obtained by training the EESIR model with results from the link level simulator.

The information passed from the link level to the system level simulator is a set of look up tables, specific for each transport format, where each look-up table includes the corresponding value of β plus the specific AWGN reference BLER curve. This curve must be obtained by simulating the complete transmission chain, including coding and interleaving, under AWGN assumptions. Based on the CQI indexes given by the LTE standard, [8], only 15 different transport formats need to be considered for the downlink. The system level simulator will then use these tables to compute the set of CQI values to be reported by each mobile node to the eNB for each RBG. The eNB needs the CQI's to perform the scheduling of downlink transmissions based on the quality reported by each mobile node in each RBG. Notice that, according to [8], the reported CQI index for a given group of resource blocks, should allow the reception of a single transport block with a BLER not higher than 0.1 after the transmission of the first H-ARQ RV. This means that the relevant BLER curves must be obtained assuming the specific code puncturing pattern that is used for the first H-ARQ RV.

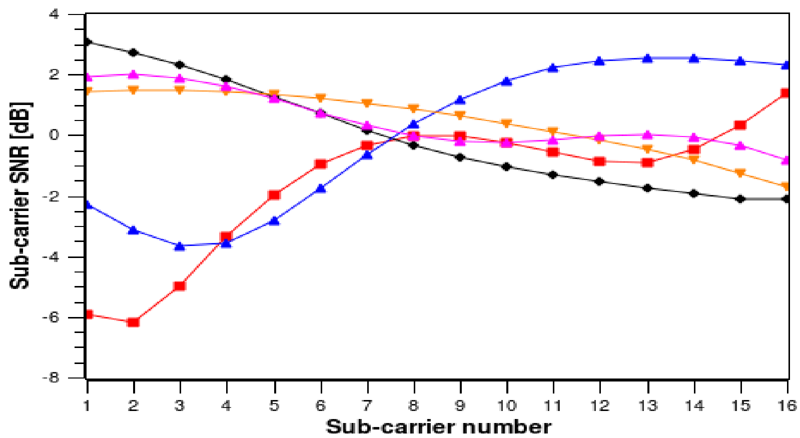

Fig. 6. Several realizations (snapshots) of the ETU multipath channel frequency response showing different frequency selective fading dynamic range. Wideband mean SNR=1dB. Subcarrier spacing=15 kHz

Next we describe the procedure that has been followed to obtain the value of β for each transport format combination. The first stage is to obtain the reference BLER curves under AWGN channel (solid lines in Fig. 7). Notice that the reference BLER curves are almost regularly spaced in steps of 2dB EESIR increase. The second stage is to generate a big number of snapshots of the mobile multipath channel with known set of measurements: $\{\gamma^i_1,\gamma^i_2,\ldots,\gamma^i_N\}$, where γ^i_k $(k=1,..,N)$ denotes the SIR for the subcarrier k and the snapshot i. For each instance of the multipath channel a big number of code blocks are simulated and a BLER measurement for the snapshot i is obtained. We call $BLER_i$ to this measurement. The channel transfer function remains constant during the simulation of a given channel snapshot. Since eq. (1) doesn't capture the frequency correlation of selective fading, a random sub-carrier interleaver is used so that frequency selective fading does not affect always the same bits in the code block. To obtain β, the EESIR of the snapshot i is expressed as a function of the unknown β, i.e.:

$$\gamma_{ef}^{i} = -\beta \ln\left(\frac{1}{N}\sum_{k=1}^{N} e^{-\frac{\gamma_k^i}{\beta}}\right) \quad (2)$$

then, if we call M to the number of simulated channel snapshots, the value of β is obtained as:

$$\beta = \arg\min\left\{\sum_{i=1}^{M}\left(BLER_i - BLER_{\mathrm{R}}(\gamma_{ef}^{i})\right)^2\right\} \quad (3)$$

where $BLER_R(\gamma)$ is the reference *BLER* curve for AWGN channel. That is, to obtain β we minimize the mean squared error between the estimated *BLER* and the measured *BLER* for the set of simulated snapshots using numerical methods.

Fig. 7 shows the fitting of EESIR model for E-UTRA DL BLER (RV=0) with SISO configuration and RBG size=1. The BLER measurements (scattered markers in Fig. 7) have been obtained using the ETU channel, [5], where the delay of the last propagation path has been taken equal to 4.69µs (instead of 5µs) to ensure that it falls within the cyclic prefix interval. This channel has been selected because it shows high frequency selectivity (see Fig. 6) but the resulting values of β are independent of the p.d.p. used for training the model. TABLE II lists the code block sizes, the obtained β and the residual r.m.s. error for each CQI. The code block sizes are the maximum that allow fitting the entire encoded block in a single TTI. For CQI≤2, and given the small code rate, one TTI has not enough capacity to transmit a single code block of the lowest size. In these cases we have assumed that the transport block can use additional subcarriers in the neighboring PRB. TABLE II applies only for RBG=1, since for RBG>1 the allowable code block sizes would be higher and the EESIR model would need retraining.

It can be noticed in Fig. 7 and TABLE II that the experimental to estimated BLER fitting degrades for the CQIs related to 64QAM. The derivation of the EESIR concept, which can be found in [6], is based on approximating the BLER as a function of the signal to noise ratios at the code symbol level, while the EESIR definition applied in this paper (see eq. (1)) relies on the subcarrier SIRs (at modulation symbol level). Since 64QAM entails unequal protection against noise for the encoded bits, the statistics of the LLRs at the code symbol level, depend on the subcarrier SIR but also on the considered modulation symbol and on the weight of the encoded bit within that symbol. So the subcarrier SIR alone can't properly predict the BLER and the EESIR concept shows higher r.m.s. error. When the code rate is close to unity, the decision relies basically on the intrinsic information (voltage of the decision variables) and BLER≈1-(1-BER)^n, where n is the encoded block size and BER is approximately 1/6 of the modulation symbol error probability, which is a function of the SIR and is quite uniform over the set of modulation symbols (since SIR≈19dB). This explains the relatively good fit of EESIR model for CQI 15.

TABLE II. VALUES OF β AND R.M.S. ERROR FOR THE COMPLETE SET OF CQI'S (SISO CONFIGURATION AND RBG SIZE=1)

CQI	**Modulation**	**Code rate**	**Turbo code block size**	**β**	**r.m.s. error**
1	QPSK	0.076	40	1.70	0.14
2	QPSK	0.117	40	1.33	0.17
3	QPSK	0.188	40	1.36	0.18
4	QPSK	0.301	72	1.79	0.15
5	QPSK	0.438	112	1.78	0.19
6	QPSK	0.588	152	1.46	0.18
7	16QAM	0.369	192	4.51	0.41
8	16QAM	0.478	248	5.26	0.46
9	16QAM	0.601	312	4.58	0.33
10	64QAM	0.455	352	4.14	1.05
11	64QAM	0.554	432	5.08	1.48
12	64QAM	0.650	512	4.95	1.82
13	64QAM	0.754	592	8.41	2.27
14	64QAM	0.852	672	15.23	1.12
15	64QAM	0.926	720	27.91	0.52

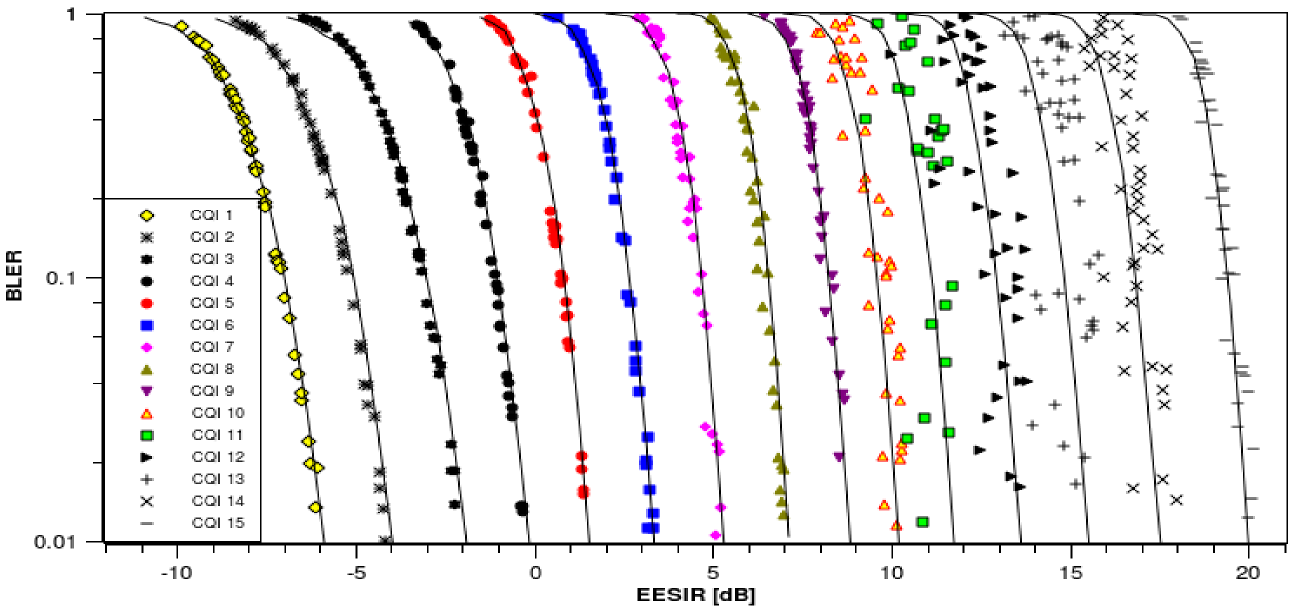

Fig. 7. E-UTRA DL BLER (RV=0) vs EESIR for SISO configuration (RBG size=1)

V. CONCLUSIONS AND FUTURE WORK

A link level simulator for LTE DL has been described. The simulator allows obtaining the suitable look-up tables to interface a system level simulator by means of the EESIR model. The mean throughput curves for different MIMO and AMC combinations have also been discussed. In future work, the EESIR reference BLER curves and parameters will be computed also for RBG of size 2, 3 and 4 and for MIMO configurations.

ACKNOWLEDGMENT

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