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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 HARQ plays a crucial role in achieving the low latency and high spectral efficiency promised by the new radio access standard. This paper presents a link level simulator for LTE downlink whose main purpose is to generate suitable look-up tables to interface with a system level simulator. The obtained results include curves of mean link level throughput for different AMC formats and MIMO configurations. The methodology for training the Exponential Effective SINR model is also described with an example.**

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 narrow band subcarrier, suitable MIMO schemes can be easily be applied on a subcarrier basis. OFDM shows an inherent frequency diversity effect if a coded block of bits is sent on a set of different subcarriers spanning a bandwidth higher that the channel coherence bandwidth. 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 (HARQ). HARQ 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 Exponential Effective SINR (EESINR) model to interface with a LTE system level simulator. Results about mean link level throughput vs mean SINR are given, as well as a methodology to train the EESINR model using the link level results.

The paper is organized as follows: section II is a description of the developed simulator, section III presents and discusses some of the obtained results, section IV describes the methodology for training the EESINR model and finally, section V includes the conclusions and future works.

II. Description of the E-UTRA DL link level simulator

In order to feed a system level simulator with the link level performances, a new 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 based rate matching and H-ARQ procedure. Variable coding rate is achieved by applying different puncturing patterns depending on the current H-ARQ incremental redundancy (IR) version. Up to four 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 a number of 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 a 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. This convention has been also followed in 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 stages. 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 (PRBs) assigned 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.

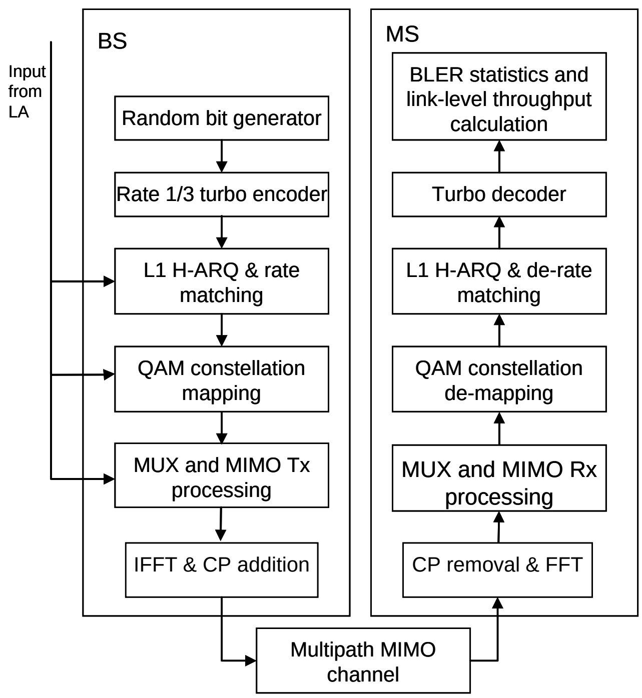

Fig. 1 Block diagram of one layer of the E-UTRA DL link level simulator

One kind of results obtained is the mean link level throughput in bit/s/Hz, for a given mean SINR and AMC format. This is evaluated as the product of the modulation spectral efficiency, the code rate and the H-ARQ retransmission efficiency. The SINR is averaged over fast fading but not over shadowing fading, which is properly modelled at system level simulation.

A second type of results are the look-up tables of β values and BLER reference curves suitable for using the EESINR link to system level simulator mapping. The methodology for obtaining these results is explained in section IV.

III. Simulation Results and Discussion

Table I lists the parameters used for the simulations. In order to achieve a high time resolution, the simulation uses the maximum bandwidth, but only one PRB is demodulated by the UE. The simulated code block sizes are the smaller ones specified for E-UTRA DL. 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 different PRB's will lead to higher throughput figures.

TABLE I
LINK AND SYSTEM 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 occupied PRBs	1
TTI length	1 ms
Number of OFDM symbols per TTI	14
Power Delay Profile	EPA channel model, [5], at Pedestrian speed 3 km/h
Channel Coding	Turbo code basic rate 1/3
Rate Matching and H-ARQ	According to [3]. Max 4 IR transmissions.
AMC formats	QPSK: 1/3, 1/2, 2/3, 4/5 16QAM: 1/2 , 2/3, 4/5 64QAM: 2/3, 4/5
Channel estimation	Ideal
Antenna scheme	SISO and MIMO

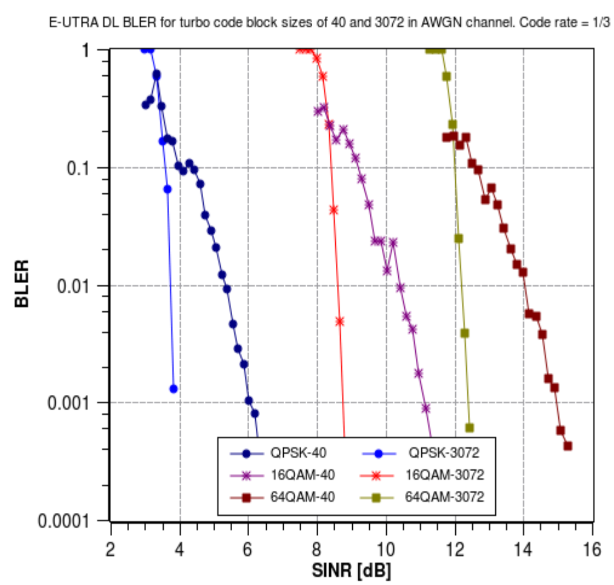

Fig. 2. BLER for two different code block sizes in AWGN channel

Fig. 2 shows the BLER in AWGN channel for turbo code block sizes of 40 and 3072 bits and different modulations.

The higher the block size the steeper is the slope of the BLER plots. A SINR increase of about 4 dB is needed to obtain the same target BLER when switching from QPSK to 16QAM and from 16QAM to 64QAM.

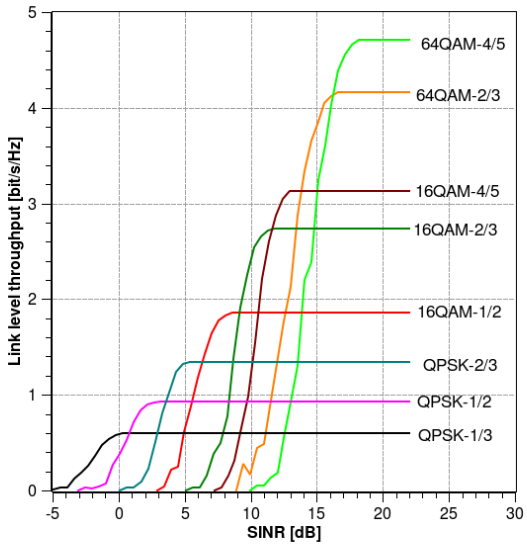

Fig. 3. Mean link throughput vs. mean SINR, for different AMC formats, in AWGN channel and turbo code block size 40-120 bits (no HARQ).

Fig. 3 shows the mean throughput vs. mean SINR in AWGN channel, without HARQ, for different AMC formats and small code block sizes. It can be observed that, in order to keep maximum throughput, the AMC format must be changed when the mean SINR increases or decreases a few dB.

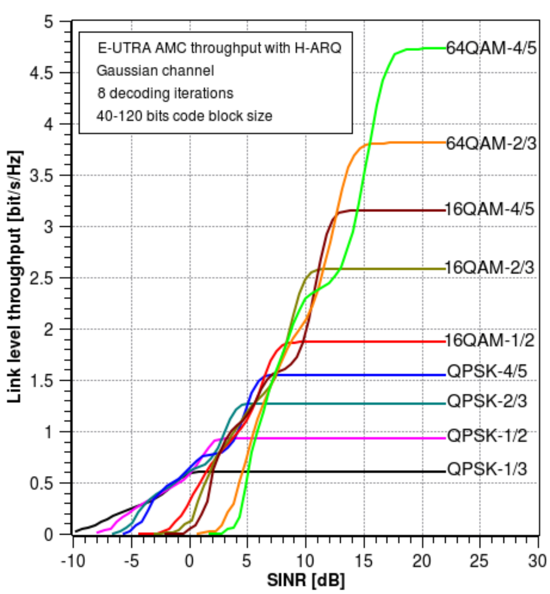

Fig. 4. E-UTRA DL AMC link level throughput with H-ARQ in Gaussian channel (Code block size: 40-120 bits)

Fig. 4 shows the mean throughput vs. mean SINR in AWGN channel, with HARQ, for different AMC formats and small code block sizes. It can be observed that now, since HARQ has smoothed the curves, it is possible to keep nearly the optimum throughput without frequent changes in the AMC format. The code rates with which the curves are labeled are approximated; this explains the difference in the saturated throughput of some AMC formats in Fig. 3 and Fig. 4.

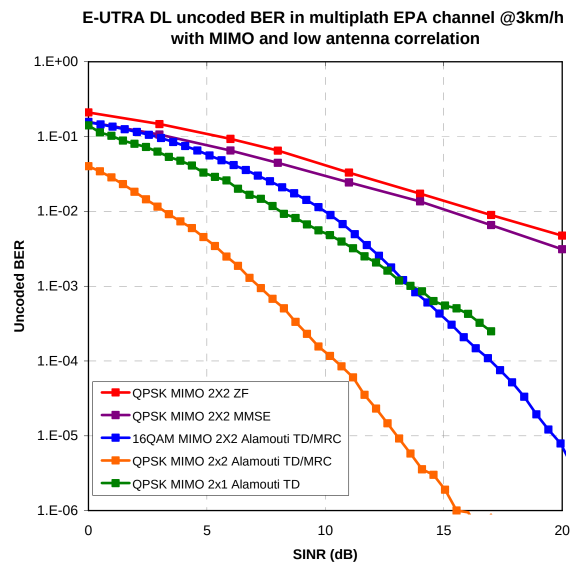

Fig. 5. Uncoded BER vs. mean SINR for different modulations and MIMO processing in EPA multipath channel @ 3km/h

Fig. 5 shows the mean uncoded BER vs. mean SINR, for QPSK and 16QAM with MIMO 2x2 in spatial multiplexing mode and in Alamouti transmit diversity mode. When using the Alamouti scheme, the two antennas at the UE (mandatory in LTE) are used to implement an order 2 MRC receiver diversity scheme. This mode gives a BER slope corresponding to a order 4 diversity. This is in contrast with the slope for an Alamouti 2x1 scheme (also shown in Fig. 5) that corresponds to a order 2 diversity. Finally, the BER slope for the MIMO spatial multiplexing modes corresponds to a typical Rayleigh environment BER curve. MMSE receiver slightly outperforms ZF receiver. The considered multipath channel model is Extended Pedestrian A (EPA), as specified in [5], with a 3km/h pedestrian speed.

Fig. 6 shows the E-UTRA DL throughput for different AMC formats in SISO mode and EPA multipath channel at a pedestrian speed of 3km/h. These results are shown only as a reference, since this configuration does not include any type of diversity, while in LTE at least Alamouti transmission diversity can always be applied even for distant users.

Fig. 7, Fig. 8 and
Fig. 9 show the E-UTRA DL throughput for different AMC formats 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.

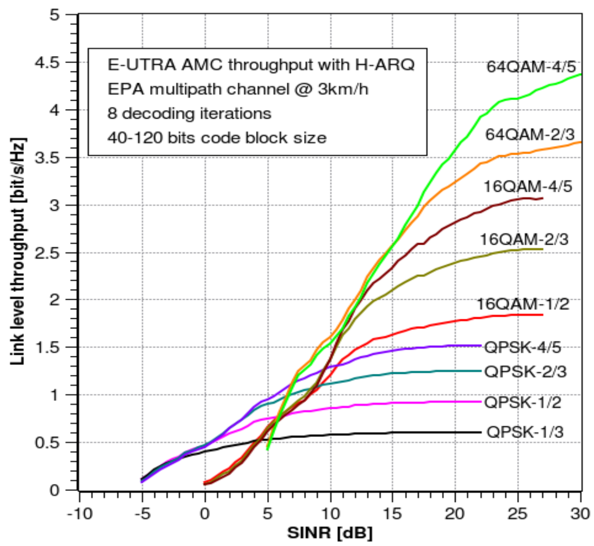

Fig. 6 E-UTRA DL AMC link level throughput with H-ARQ in multipath EPA channel 3km/h

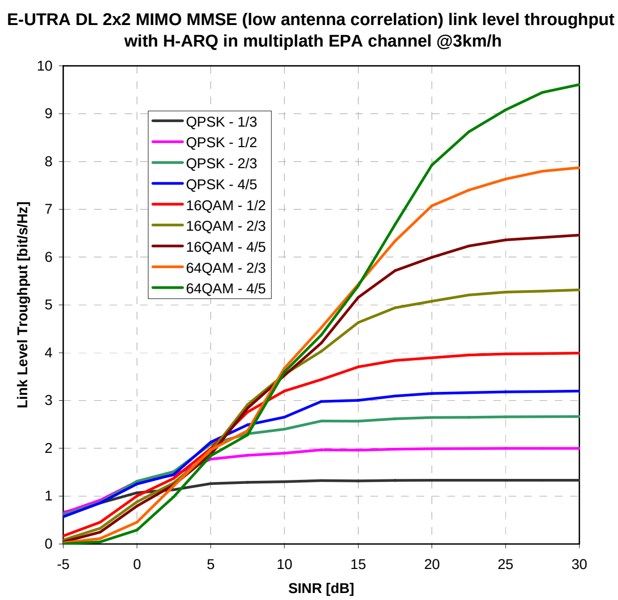

Fig. 7 E-UTRA DL 2x2 MIMO MMSE link level throughput with H-ARQ in multipath EPA channel 3km/h and low antenna correlation

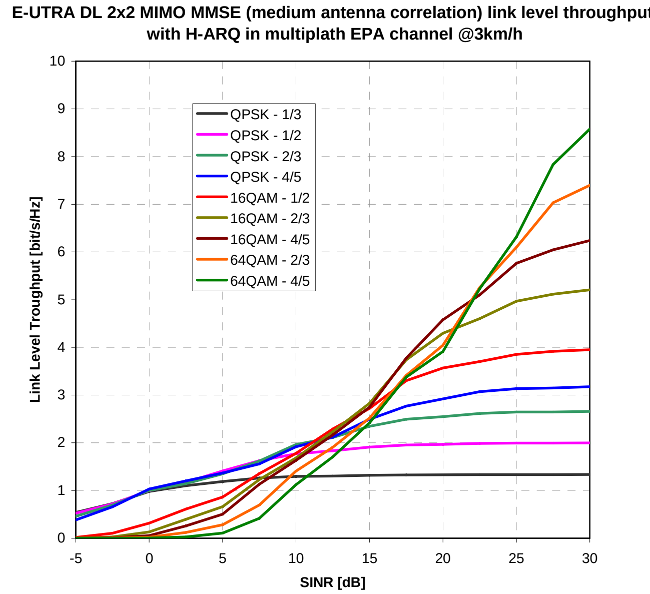

Fig. 8 E-UTRA DL 2x2 MIMO MMSE link level throughput with H-ARQ in multipath EPA channel 3km/h and medium antenna correlation

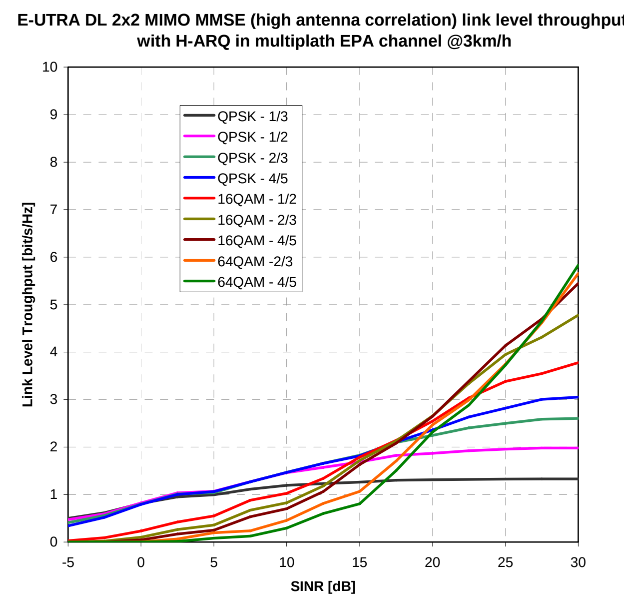

Fig. 9 E-UTRA DL 2x2 MIMO MMSE link level throughput with H-ARQ in multipath EPA channel 3km/h and high antenna correlation

IV. Training of the Exponential Effective SIR 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 SINR 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 vehicles 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], the concept of EESINR is introduced to account for multistate channels while still being able to use the AWGN BLER vs SINR curve as a reference for the BLER estimation under real conditions.

For a given multistate channel with *N* different SINR measurements $\{\gamma_1,\gamma_2,\ldots,\gamma_N\}$, the EESINR is defined as the value, γ_{ef}, that accomplishes the equation:

$$I(\gamma_{ef}) = \frac{1}{N}\sum_{k=1}^{N} I(\gamma_k) \qquad (1)$$

where *N* depends on the frequency resolution of the measurements available at the mobile node. Since one value of the EESINR for each group of resource blocks is required to report the CQI's according to the LTE specifications, the value of *N* should span a bandwidth equivalent to a resource block group (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 function $I(\gamma)$ in (1) is given by:

$$I(\gamma) = 1 - e^{-(\gamma/\beta)} \qquad (2)$$

So, the EESINR can be isolated from (1) as:

$$\gamma_{ef} = -\beta \ln\left(\frac{1}{N}\sum_{k=1}^{N} e^{-\frac{\gamma_k}{\beta}}\right) \qquad (3)$$

The parameter β allows adjusting the real BLER curve 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. (3), the EESINR concept summarizes all these measurements in a single scalar value. The value of β, specific for a given modulation, code block size and code rate, must be obtained by training the EESINR 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 UE 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 HARQ redundancy version. This means that the relevant BLER curves must be obtained assuming the specific code puncturing pattern that is used for the first HARQ redundancy version.

Next we describe the procedure that has been followed to obtain the value of β for each transport format combination. The first step is obtaining the reference BLER curve under AWGN channel, see Fig. 10. The second step is to generate a 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 SINR for the subcarrier *k* and the snapshot *i.* In practice the value of *N* should be selected big enough to have sufficient frequency resolution (with respect to the coherence bandwidth of the channel) and to span the RBG that we want to characterize. 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 all the simulation. Then, the EESINR of the snapshot *i* is expressed as a function of the unknown β, i.e.:

$$\gamma^i_{ef} = -\beta \ln\left(\frac{1}{N}\sum_{k=1}^{N} e^{-\frac{\gamma^i_k}{\beta}}\right) \qquad (4)$$

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

$$\beta = \arg\min\left\{\sum_{i=1}^{M}\left(BLER_i - BLER_{\mathrm{R}}(\gamma^i_{ef})\right)^2\right\} \qquad (5)$$

where $BLER_R(\gamma)$ is the reference curve for AWGN channel. That is, we minimize the mean square error between the estimated *BLER* and the measured *BLER* for the set of simulated snapshots using numerical methods. Since all the constants are known, the expression between brackets in (5) is in fact a single function of β in a closed form that must be minimized. Fig. 10 summarizes the methodology explained above. The parameters of the simulation are shown in the same figure. In this example, the simulated multipath channel is the Extended Typical Urban (ETU) channel, see [5].

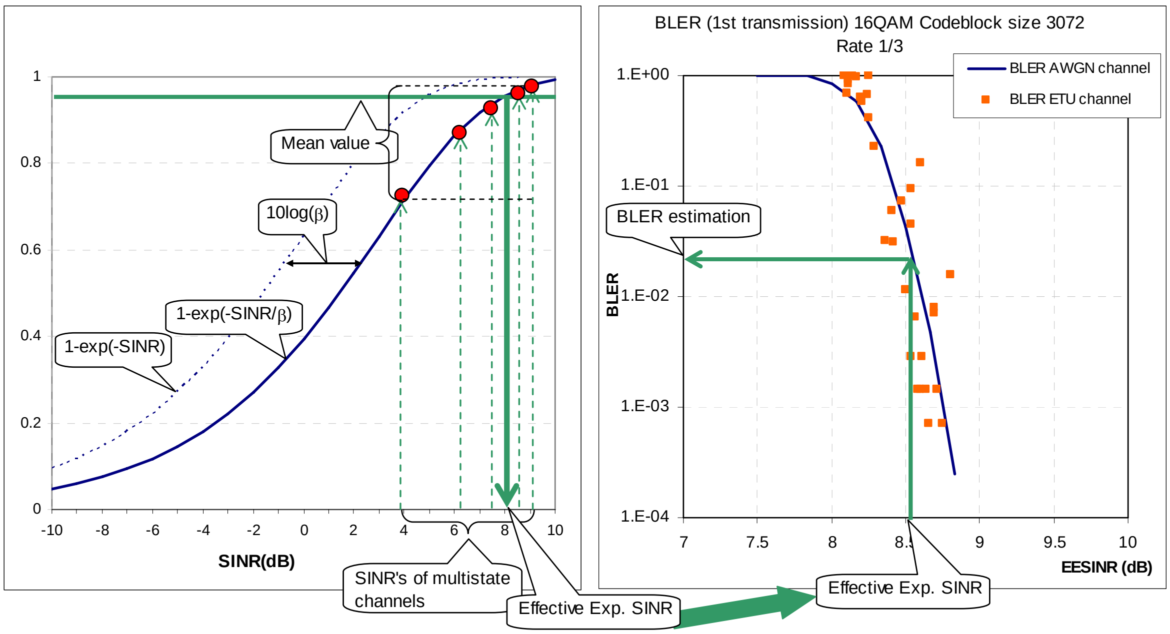

Fig. 10. Example of EESINR and β parameter computation

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 EESINR model. Several throughput curves for different MIMO and AMC combinations have been discussed. The results show the expected behavior and are aligned with those previously reported in the available literature. In future work, the complete set of look-up tables for the EESINR link to system level simulator mapping will be computed.

Acknowledgment

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