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Imran Latif, Florian Kaltenberger, Navid Nikaein, Raymond Knopp
EURECOM
Campus SophiaTech, Les Templiers,
450 Route des Chappes,
06410 Biot, France

Phone: +33 4 93 00 81 67
Fax: +33 4 93 00 82 00
Email: {latif,kaltenbe,nikaein,knopp}@eurecom.fr

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Imran Latif, Florian Kaltenberger, Navid Nikaein, Raymond Knopp
Eurecom
Campus SophiaTech, Les Templiers,
450 Route des Chappes,
06410 Biot, France
Email: (first name.last name)@eurecom.fr

Abstract

In wireless communications the evaluation of large scale systems with the help of system simulators is of utmost importance. However, these simulations have a high computational complexity due to the physical layer (PHY) algorithms and the channel model used. Many system level simulators therefore rely on PHY abstraction techniques that predict the performance of the PHY based on the current channel state. The OpenAirInterface (OAI) LTE system level simulator is one of the only tools that can be either run with a full PHY or with PHY abstraction. In this paper we present the complete methodology of expected effective SINR mapping (EESM) based PHY abstraction for OAI LTE system level simulator. We present the methodology for not only single-input single-output (SISO) communication but also for multiple-input multiple-output (MIMO) communication in LTE. We show with the help of results that implemented PHY abstraction improves the simulation time by a factor of 30 while providing the same accuracy as the full PHY implementation.

I. Introduction

Long term evolution (LTE) and LTE-Advanced are the recent cellular systems standardized by the third Generation Partnership Project (3GPP). These standards promise to achieve the data rates of the order of hundreds of mega bytes per second (MB/s) on the mobile devices and are shown to be spectrally efficient. This is mainly because of the use of OFDM as modulation scheme, support of multiple antennas at transmitter and receiver, use of capacity achieving turbo codes and HARQ at the layer 1 (L1). However the gains offered by these techniques on the single communication link do not necessarily represent the same gains when deployed in a huge system. Therefore the system level simulations are necessary for the evaluation of these techniques before their deployment. System level simulations normally require heavy computations for extremely long duration of time because of the characterization of the radio links between each user and base station. The link level simulations of all such links is the bottle neck in these kind of simulations. Therefore, to reduce the complexity and duration of system level simulations we need to have an interface which replaces the actual link level computations and provides the higher layers with necessary and accurate link quality metric, i.e., block error rate (BLER) or packet error rate (PER).

PHY abstraction, also referred as link-to-system mapping and link prediction, provides such an interface between system level simulators and link level simulators for the large scale system simulations. This interface is normally a metric representing the quality of an instantaneous physical link (channel) between the eNodeB (LTE acronym for base station) and the connected UEs (LTE acronym for mobile station) by taking into account other important parameters of the system. These parameters may include the knowledge about power and resource allocation to the specific UE, number of spatial layers, modulation and coding scheme (MCS), and mainly channel characteristics, i.e., path loss, shadowing, fading, interference etc. The use of PHY abstraction in system evaluations should provide four main benefits, 1) low complexity and speed by replacing the complete physical layer processing with a rather simple calculations using table look ups, 2) scalability in system evaluations by making it possible to evaluate huge systems with hundreds of nodes, 3) applicability in diverse use cases and finally 4) the most important is realism of providing the true link quality metric as it would have obtained with full PHY processing.

PHY abstraction is rather trivial for the frequency flat channels as the simple averaging of channel qualities is sufficient for link quality mapping but for highly frequency selective channels the performance evaluation is not that trivial. This is mainly because of the smaller coherence bandwidth than that of the signal bandwidth giving rise to the multi-state channel at the receiver. However to address this issue many link abstraction techniques have been proposed in the literature for these multi-state channels. EESM was first introduced in [7] for system level evaluations and since then it has been extensively used for link quality modeling. In [8] it is shown that EESM is a suitable choice for 3GPP LTE wireless systems and it outperforms the other schemes. Further it was demonstrated with the help of results that training of link abstraction is independent of the used channel model. Whereas in our findings it was observed that if the training is performed over the data set of a very

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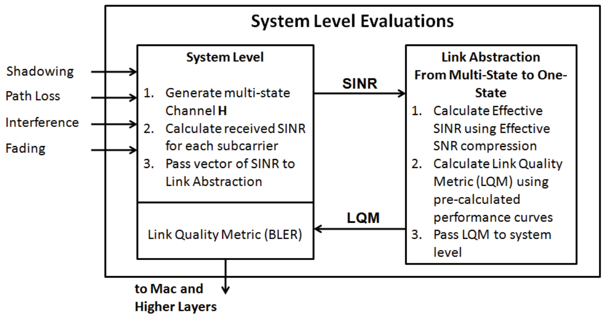

Fig. 1. Link Abstraction in System Performance Evaluation

large number of channel realizations corresponding to the highly frequency selective channel then the resulting calibration is capable of modeling a diverse range of multi-state channels. In [5] authors discussed some of the possible link performance models and evaluated them in terms of complexity and performance. They showed through their results that mutual-information based effective SINR mapping (MIESM) performs better in both complexity and performance than other approaches. In [9] the authors have used the observation that decoding of a codeword is independent of modulation so they have devised a two step method where received bit information rate is used as a link quality measure instead of effective SINR. This method is also mutual information based and does not require the calibration for convolution and turbo decoders. In [6] (Wireless World Initiative New Radio- WINNER) MIESM was selected as the link performance modeling methodology.

II. OpenAirInterface

OpenAirInterface is an open-source platform for experimentation in wireless systems with a strong focus on cellular technologies such as LTE and LTE-Advanced. The platform comprises both hardware and software components and can be used for simulation/emulation as well as real-time experimentation. It comprises the entire protocol stack from the physical to the networking layer. The objective of this platform is to fill the gap between the simulation and real experimentation by providing the baselines for protocol validation, performance evaluation and pre-deployment system test. The key features are

- Extensive LTE Release 8.6 compliance with some features from LTE-Advanced
- Full protocol stack for both UE and eNB implementations
- Provides Linux networking interface to run any application on top
- Carrier aggregation possible
- Implements several important transmission modes (TM) of LTE
  - LTE TM 1 (SISO)
  - LTE TM 2 (STBC - Alamouti Codes)
  - LTE TM 5 (MU MIMO)
  - LTE TM 6 (Transmit Precoding)

OpenAirInterface comprises a highly optimized C implementation all of the elements of the 3GPP LTE Rel 8.6 protocol stack for UE and eNB (PHY, MAC, RLC, RRC, PDCP, NAS driver). Apart from real-time operation of the software modem on a hardware target, the full protocol stack can be run in emulation. The OpenAirInterface emulation environment allows for virtualization of network nodes within physical machines and distributed deployment on wired Ethernet networks. Nodes in the network communicate via direct-memory transfer when they are part of the same physical machine and via multicast IP over Ethernet when they are in different machines. In the first case the emulator can either be run with the full PHY layer or with PHY abstraction while in the latter case nodes interface at layer 2. The rest of the protocol stack (MAC and RLC) for each node instance uses the same implementation, as would the full system. Each node has its own IP interface that can be connected either to an application or a traffic generator. The emulator also comprises a simple mobility model and channel models including path loss, shadow fading and stochastic small scale fading.

III. LTE System Model

In this paper we consider an LTE single cell scenario with one eNodeB and K active UEs. The eNodeB is equipped with N_t antennas whereas the UEs are equipped with single antenna only. The scheduler decides to schedule the U users out of the K available users depending on their channel conditions and the requested bandwidth. Further the eNodeB can be configured to serve the UEs in different available transmission modes. However in this paper we shall discuss only LTE TM 1, 2 and 6. Since LTE TM 1 represents a SISO system so $N_t = 1$ whereas TM 2 and 6 represent MISO systems with $N_t = 2$. The received signal for SISO transmission in LTE at u-th UE on n-th resource element is given by

$$y_{u,n} = h_{u,n} x_{u,n} + z_{u,n}, \quad n = 1, 2, \cdots, N$$

where $h_{u,n} \in \mathbb{C}$ symbolizes the SISO channel from the eNodeB to u-th UE, $z_{u,n}$ is ZMCSCG white noise of variance N_0 at u-th UE, complex symbol $x_{u,n}$ is assumed to be independent and belong to discrete M-QAM constellations with variance σ_u^2

In transmission mode 2, two complex symbols (i.e. x_1 and x_2) are transmitted over two symbol times from the two transmit antennas. We assume that the channel is i.i.d but stays constant for the duration of the two symbol times. In the first symbol time x_1 and x_2 are transmitted whereas in the second symbol time $-x_2^*$ and x_1^* are transmitted through antenna 1 and antenna 2 respectively. The received signal for transmission mode 2 at u-th UE on n-th resource element after two symbol times is given by

$$\mathbf{y}_{u,n} = \mathbf{X}_{u,n}\mathbf{h}_{u,n} + \mathbf{z}_{u,n}, \quad n = 1, 2, \cdots, N$$

$$\mathbf{X}_{u,n} = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix}, \mathbf{h}_{u,n} = \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} \text{ and } \mathbf{z}_{u,n} = \begin{bmatrix} z_1 \\ z_2 \end{bmatrix}$$

where $\mathbf{h}_{u,n} \in \mathbb{C}^{2\times 1}$ is the MISO channel from eNodeB to the u-th UE, $\mathbf{X}_{u,n}$ is 2×2 matrix in which each column represents the 2×1 vector of independent complex symbols x_1 and x_2 of variance σ_u^2 at u-th UE for two symbol periods, $\mathbf{z}_{u,n}$ is vector of ZMCSCG white noise of variance N_0 at u-th UE for two symbol periods.

In transmission mode 6 a high SNR is obtained at the receiver by using transmit precoder p which focuses the transmit energy to specific user. The received signal for MISO transmission at u-th UE on n-th resource element is given by

$$y_{u,n} = \mathbf{h}_{u,n}^{\dagger}\mathbf{p}_{u,n}x_{u,n} + z_{u,n}, \quad n = 1, 2, \cdots, N$$

where $\mathbf{h}_{u,n}^{\dagger} \in \mathbb{C}^{1\times 2}$ symbolizes the MISO channel from the eNodeB to u-th UE, $\mathbf{p}_{u,n}$ is the precoder requested by u-th UE and $z_{u,n}$ is ZMCSCG white noise of variance N_0 at u-th UE. In LTE the user can request one of the four available precoders, $\mathbf{p} = [1 \quad q]^T, \quad q \in \{\pm 1, \pm j\}$, with the help of feedback in order to be served in transmission mode 6.

A. Overview of Effective SINR Mapping (ESM)

The two most studied link abstraction methodologies are the expected effective SINR mapping (EESM) and mutual-information based effective SINR Mapping (MIESM). In both of the two methods the basic scheme is effective SINR mapping which at first maps the varying SINRs of a codeword to an effective SINR (γ_{eff}) value which is then used to read the equivalent BLER from the AWGN performance curves of a particular modulation and code scheme (MCS).

$$\gamma_{eff} = \beta_1 I^{-1}\left[\frac{1}{N}\sum_{n=1}^{N} I\left(\frac{\gamma_n}{\beta_2}\right)\right] \tag{1}$$

$$\gamma_{eff} \rightarrow BLER(mcs) \tag{2}$$

Where N is the number of channel symbols in a codeword and $I(\gamma_n)$ is a mapping function which transforms SINR of each channel symbol to some "information measure" where it is linearly averaged over the codeword. Then these averaged values are transformed back to SNR domain. β_1 and β_2 are called calibration factors and they are there to compensate for different modulation orders and code rates.

For the EESM the mapping function $I(\gamma_n)$ is calculated using Chernoff Union bound of error probabilities[7], i.e.,

$$I(\gamma_n) = 1 - \exp(-\gamma_n) \tag{3}$$

$$\gamma_{eff} = -\beta_1 \ln\left[\frac{1}{N}\sum_{n=1}^{N} \exp\left(-\frac{\gamma_n}{\beta_2}\right)\right] \tag{4}$$

For the mutual information based methods the approximations of mapping function and the reverse mapping functions come from the mutual information for discrete QAM constellation, i.e.

$$I_{M_1}(\gamma_j) = \log M_1 - \frac{1}{M_1}\sum_{x_1 \in \chi_1} \mathcal{E}_{z_1} \log \frac{\sum_{x_1' \in \chi_1} \exp\left[-\left|\gamma_j\left(x_1 - x_1'\right) + z_1\right|^2\right]}{\exp\left[-|z_1|^2\right]} \tag{5}$$

where χ_1 is the set of the QAM constellation points with $|\chi_1| = M_1$ and $z_1 \in \mathcal{CN}(0,1)$.

EESM has been chosen for the system evaluations by 3GPP for LTE therefore in this paper we shall be using EESM in PHY abstraction for LTE system level evaluations.

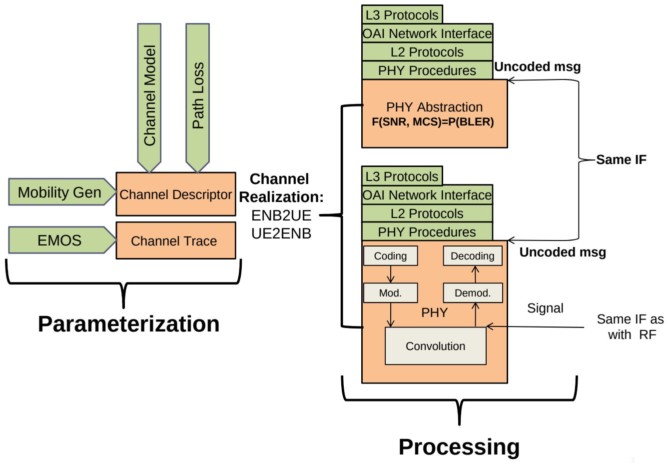

Fig. 2. PHY Abstraction in System Performance Evaluation in OpenAirInterface

IV. PHY Abstraction in OpenAnirInterface

A. Overview

In OpenAirInterface the required parameters for large scale system simulations are highly dynamic and can be generated either by the specialized tools already included in the simulator, i.e., openair traffic generator, openair mobility generator etc, or these parameters can be specified explicitly in great details for the specific scenarios and evaluations. The use of PHY abstraction in OpenAirInterface system simulator is explained in Figure 2.
It can be seen from the Figure 2 that there are two important steps in any evaluation using OpenAirInterface, parameterization and processing. It is important to note that parameterization is independent of the knowledge about the PHY abstraction. The output (channel realizations) from parameterization step is given to the processing where the comparison between using the full PHY and PHY abstraction is shown. It can be seen that in the case of PHY abstraction there is no coding, decoding or other complex operations involved from the transceiver chain at the physical layer (L1) only. The main purpose of the physical layer is to inform the higher layers about the status of the decodability of data packet. If the decoding is successful then the higher layers are notified about it. However in the case of using PHY abstraction this is achieved by predicting a link quality metric in terms of block error probability from the instantaneous channel realizations across all of the subcarriers. After the BLER is calculated using PHY abstraction, a random number between 0 and 1 is generated which is compared with this BLER for taking the decision on the successful or unsuccessful transmission. Then the outcome of this probabilistic experiment is passed to the higher layers which perform their tasks independent of the knowledge about the PHY abstraction.

B. Effective SINR Calculation

The most important step in PHY abstraction is to calculate the effective SINR in a way that it is able to transform the multi-state channel in to a single state channel. But this is dependent on the post processed SINR value. The post processed SINR values depend on the receiver and the transmission mode. For the transmission mode 1, 2 and 6 with an MMSE receiver, these can be calculated as,

$$\gamma_{n,1} = \frac{|h|^2}{N_0} \tag{6}$$

$$\gamma_{n,2} = \frac{|h_1|^2 + |h_2|^2}{N_0} \tag{7}$$

$$\gamma_{n,6} = \frac{|h_1 + qh_2|^2}{N_0} \tag{8}$$

Using (4) and $\gamma_{n,t}$, where $t \in \{1, 2, 6\}$ represents the transmission mode, γ_{eff} is calculated. Then finally this γ_{eff} is used to read the BLER from previously calculated AWGN performance curves corresponding to the specific MCS, i.e.,

$$BLER(\boldsymbol{\gamma}, mcs) \simeq BLER_{AWGN}(\gamma_{eff}, mcs) \tag{9}$$

Where $\boldsymbol{\gamma}$ represents the $N \times 1$ vector of γ_n.

V. Results

A. Link Level Validation

In order to train and test the PHY abstraction for system level evaluations, first it had to be validated through link level simulator, therefore, we used Eurecom's OpenAirInterface[1] link level simulator which is completely programmed in C language for its applicability to hardware as well. It implements 3GPP LTE Release 8.6 physical layer [2], [1], [3] and works with 5MHz bandwidth (though it can recently be used for higher bandwidths as well). There are 25 physical resource blocks (PRB) in this bandwidth and it uses TDD UL/DL Frame Configuration 3 from the 3GPP standard [2] which has 6 downlink (DL) subframes, 3 uplink (UL) subframes and a special subframe with configuration 0 (i.e., longest guard interval). One can use either normal or extended cyclic prefix for the simulations but in our simulations we used normal cyclic prefix. It can perform simulations for all of the LTE MCS (0-28) for different types of channels, i.e. Rayleigh, Ricean, EPA, ETU, SCM etc. It also implements both ideal and real channel estimation. For our results we used ideal channel estimation with 8-tap Rayleigh channel model with the delay spread of 1e-6 seconds. For each of the transmission mode and each of the MCS, we performed link level simulations for more than 100 different channel realizations. We kept the channel constant during each of the channel realization and simulated the system for 10000 packets or 5000 erroneous packets with random AWGN noise. From these simulations we saved the $BLER_{meas,mcs}$ and other required parameters necessary for the link abstraction. The next important step is to calibrate the adjustment factors. The calibration of these factors should be performed with such a channel model which can provide it with high frequency selectivity that is why we chose Rayleigh Channel model and then we performed this step over large number of channel and noise realization to find adjustment factors such that

$$(\beta_1, \beta_2) = \underset{(\beta_1,\beta_2)}{\operatorname{argmin}} [\text{MSE}]$$

$$\text{MSE} = \sum_{i=1}^{N_{ch}} \left| BLER_{pred,mcs}(\beta_1, \beta_2) - BLER_{meas,mcs} \right|^2$$

where MSE is the mean squared error, N_{ch} is the number of different channel realizations, $BLER_{pred,mcs}$ is the predicted block error rate from the respective AWGN curve calculated before hand from the simulator and $BLER_{meas,mcs}$ is the error rate from the N_{ch} channel realizations. To obtain the $BLER_{pred,mcs}$ we performed AWGN link level simulations for all MCS of LTE and stored these AWGN SNR-BLER performance curves to be used for the prediction of BLER during the optimization of adjustment factors β_1 and β_2. These are shown in Figure 3.

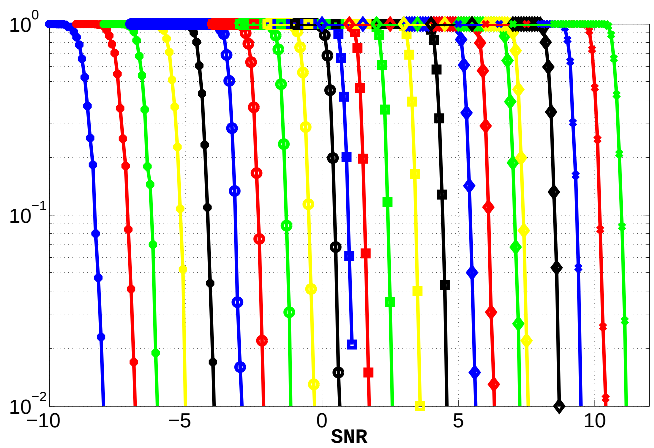

Fig. 3. AWGN Link Performance Curves in LTE with 5 MHz Bandwidth for MCS 0 - 22

We also performed the calibration when both of the calibration factors are equal, i.e., $\beta_1 = beta_2$ and we observed that for the ideal channel estimation, single beta calibration is also sufficient. After calibration we applied the PHY abstraction on the saved outputs of simulations. Results of which are shown in figures below. The solid magenta lines represent the AWGN curves whereas the points around awgn curves are the $BLER_{meas,mcs}$ after the mapping. Also we have provided the tables where we present the calibration factors with MSE and it can be seen that the MSE is very low. Which means that the link abstraction is accurate and maps the instantaneous channel realizations onto the corresponding AWGN realizations very well even in the case of highly frequency selective channels.

[1] http://www.openairinterface.org/

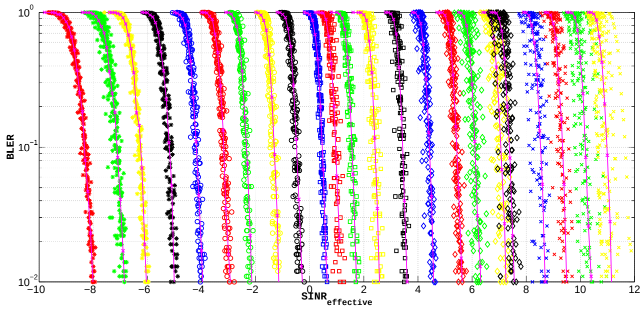

Fig. 4. LTE Transmission Mode 1 - EESM with two calibration factors for MCS 0 - 22

TABLE I
LTE TRANSMISSION MODE 1 - CALIBRATION FACTORS AND MEAN SQUARED ERROR (MSE) VALUES FOR EESM ABSTRACTION

MCS	β_1	β_2	MSE	$\beta_1 = \beta_2$	MSE
0	2.51867	2.49808	0.00391	1.67227	0.00419
1	0.48797	0.48677	0.01437	0.48037	0.01441
2	0.51811	0.51144	0.00526	0.48369	0.00623
3	1.15845	1.14284	0.00891	1.00752	0.00991
4	0.79600	0.79522	0.00578	0.79189	0.00579
5	0.77935	0.77683	0.00493	0.76982	0.00500
6	0.80905	0.79431	0.00708	0.75635	0.00815
7	0.80876	0.79535	0.00842	0.76934	0.00960
8	0.80563	0.81064	0.00919	0.81943	0.00930
9	0.84083	0.82789	0.00576	0.81045	0.00628
10	1.91969	1.85813	0.01039	1.68115	0.01512
11	1.95414	1.90448	0.00708	1.76328	0.00867
12	2.35630	2.26533	0.01159	2.05742	0.01980
13	2.48046	2.41211	0.01111	2.30283	0.01494
14	2.41703	2.37478	0.01093	2.29941	0.01216
15	2.99274	2.92132	0.01046	2.79570	0.01242
16	2.84205	2.87155	0.02203	2.92852	0.02243
17	5.27602	5.02621	0.03266	4.57061	0.04196
18	5.75658	5.42143	0.03246	4.97412	0.05246
19	6.48658	6.08509	0.03809	5.49932	0.04263
20	7.79768	7.18738	0.02389	6.27109	0.04122
21	7.78316	7.46862	0.06827	6.96455	0.07076
22	7.49917	7.51829	0.07799	7.54385	0.07801

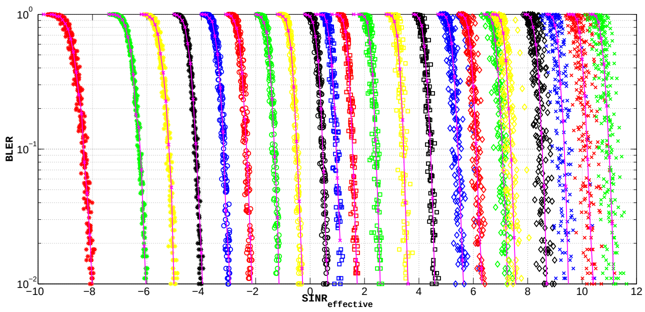

Fig. 5. LTE Transmission Mode 2 - EESM with two calibration factors for MCS 0 - 22

B. System level implementation and validation

Link level results show that our approach for the PHY abstraction is very much accurate and can be used in system level simulators. Therefore we decided to implement it in the OAI system level simulator [4]. This system level simulator implements the full protocol stack for different transmission modes of LTE. We wanted to show that how the link abstraction can provide us with 1) low complexity and speed 2) scalability 3) applicability and most importantly 4) accuracy. To show all these we performed system level simulations for different transmission modes both with full PHY and PHY abstraction. The underlying

TABLE II
LTE TRANSMISSION MODE 2 - CALIBRATION FACTORS AND MEAN SQUARED ERROR (MSE) VALUES FOR EESM ABSTRACTION

MCS	β_1	β_2	**MSE**	$\beta_1 = \beta_2$	**MSE**
0	0.51505	0.51133	0.00469	0.45410	0.00500
2	0.72291	0.71876	0.00205	0.67930	0.00233
3	0.69201	0.68623	0.00354	0.62822	0.00388
4	0.72305	0.71997	0.00282	0.69775	0.00292
5	0.69175	0.68011	0.00263	0.61719	0.00450
6	0.74296	0.71927	0.00433	0.63203	0.01021
7	0.79333	0.76209	0.00280	0.61602	0.01017
8	0.79476	0.76746	0.00326	0.69336	0.00981
9	0.77145	0.72608	0.00322	0.64648	0.01661
10	1.79586	1.69821	0.00606	1.34043	0.02817
11	1.63912	1.57082	0.00369	1.31064	0.01079
12	1.90221	1.82649	0.00694	1.55771	0.01327
13	2.31685	2.17287	0.00871	1.81406	0.03317
14	2.66179	2.44757	0.00491	1.86338	0.04119
15	2.29127	2.17064	0.02918	1.87451	0.03991
16	3.11592	2.86310	0.00963	2.26924	0.03754
17	4.46069	4.08881	0.01218	3.25967	0.05211
18	5.21514	4.62933	0.02739	3.39932	0.08052
19	5.96413	5.21403	0.02564	3.99404	0.10190
20	6.46220	5.54003	0.07693	3.98320	0.19211
21	7.60083	6.46778	0.06793	4.82715	0.20850
22	9.87314	8.17512	0.04159	5.88779	0.18040

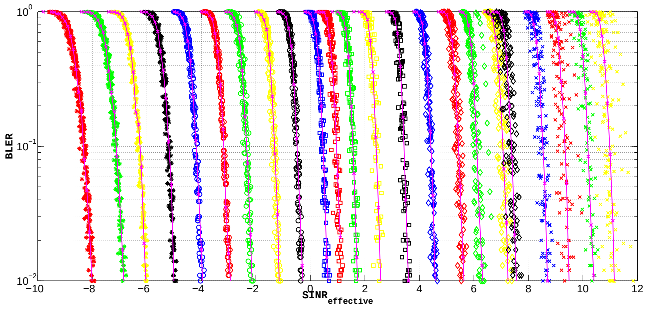

Fig. 6. LTE Transmission Mode 6 - EESM with two calibration factors for MCS 0 - 22

scenario consists of a system with one eNodeB and two UEs. We specified the system scenarios through parameters file and ran the simulator for 500 frames. During the simulations we calculated both the accumulated averaged throughput of system over given number of frames and also the execution time for the simulation. To show that using PHY abstraction is less complex and it speeds up the evaluation process we stored the execution time for system simulations of same scenarios with full PHY and PHY abstraction. We stored these times under Linux operating systems when there was no other application running but the simulation only. We found out that simulations with abstraction took extremely short time than that of with full PHY. The calculated speedup factor for PHY abstraction was found to be around 30 when compared to the time for full PHY. Table shows the execution time for the simulation and it is clear from the results that PHY abstraction speeds up the process very drastically. The next important thing to demonstrate is the realism of abstraction in system level evaluations. By realism we mean that the simulations with PHY abstraction should produce the results similar to the simulations with full PHY. This is shown by plotting the accumulated average throughput of the system over a given number of frames in Figures 7, 8 and 9 for transmission mode 1, 2 and 6 respectively. It is very clear that performance of both full PHY and PHY abstraction is very much close to each other and provide the same system throughput. Another important aspect to note is that although we calibrated the adjustment factors with Rayleigh channel model but to show the applicability of PHY abstraction in diverse channel models we used different channel models for the simulations of these transmission modes. For example simulation for the TM 1 was performed with 8-tap Ricean channel, simulation for TM 2 with 8-tap Rayleigh channel and simulation for TM 6 with single tap Ricean channel. It is clear that the calibrated factors for Rayleigh channel are also applicable to other channel models thus giving rise to its applicability. In the end we shall like to discuss that although we performed these simulations with small number of users but still it shows the significant advantages of using PHY abstraction over full PHY. Further it can be straight forwardly inferred that in the case of more UEs in the system, the gains achieved from PHY abstraction will

TABLE III
LTE TRANSMISSION MODE 6 - CALIBRATION FACTORS AND MEAN SQUARED ERROR (MSE) VALUES FOR EESM ABSTRACTION

MCS	β_1	β_2	MSE	$\beta_1 = \beta_2$	MSE
0	0.43114	0.42671	0.00391	0.36455	0.00451
1	0.57761	0.56792	0.00349	0.45781	0.00504
2	0.69824	0.69631	0.00221	0.67275	0.00225
3	0.70350	0.69631	0.00364	0.63955	0.00418
4	0.72077	0.71818	0.00285	0.69434	0.00290
5	0.71127	0.69330	0.00147	0.60400	0.00541
6	0.70513	0.68993	0.00390	0.61895	0.00670
7	0.80003	0.76490	0.00381	0.65205	0.01267
8	0.81582	0.77642	0.00311	0.65488	0.01643
9	0.78684	0.74239	0.00354	0.65449	0.01698
10	1.81199	1.73499	0.00551	1.49326	0.01911
11	1.80174	1.72851	0.00372	1.46436	0.01407
12	2.34708	2.19196	0.00706	1.68008	0.02873
13	2.59607	2.41612	0.00578	1.80293	0.02235
14	2.57389	2.38144	0.00385	1.90117	0.03166
15	2.81933	2.59327	0.00866	2.09092	0.02814
16	2.70396	2.53965	0.02087	2.23428	0.03893
17	4.93805	4.43685	0.01588	3.20693	0.05031
18	4.84900	4.46593	0.01656	3.69316	0.04281
19	6.80857	5.92575	0.01480	3.87373	0.06926
20	7.04470	6.27926	0.04026	5.06602	0.07907
21	9.33852	8.03885	0.01717	5.73379	0.10818
22	9.96321	8.28751	0.06238	6.04336	0.16304

TABLE IV
SIMULATION TIMES DIFFERENT TRANSMISSION MODES

		Time in minutes and seconds	
		Full PHY	PHY Abstraction
TM 1	real time	2m26.602s	0m6.794s
	user CPU time	2m25.633s	0m6.480s
	system CPU time	0m0.924s	0m0.328s
TM 2	real time	4m1.607s	0m9.085s
	user CPU time	3m59.079s	0m8.753s
	system CPU time	0m1.940s	0m0.364s
TM 6	real time	2m19.320s	0m7.027s
	user CPU time	2m18.473s	0m6.752s
	system CPU time	0m0.824s	0m0.300s

be even significant while maintaining the realism of evaluations.

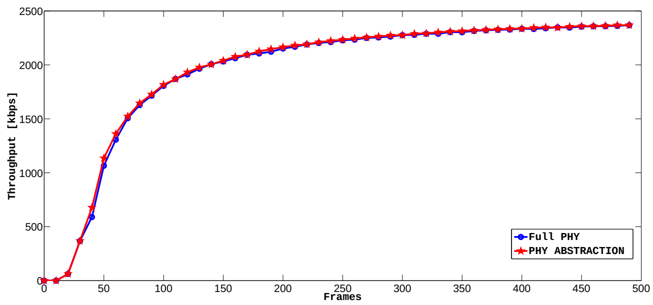

Fig. 7. LTE Transmission Mode 1 - Accumulated average system throughput over given number of frames

VI. CONCLUSION

In this paper we have presented the complete methodology about the implementation of PHY abstraction in LTE systems using OpenAirInterface. We not only provided the details of training and validation of PHY abstraction with the help of link level simulator but also showed that how it is implemented in OAI system level simulator. Further we demonstrated that using PHY abstraction provides speed (upto the factor of 30 as compared to full PHY), realism and scalability in system evaluations. It was also shown that this kind of PHY abstraction increases the applicability of OAI system level simulator

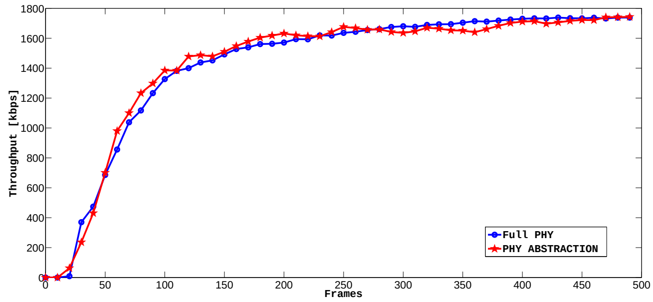

Fig. 8. LTE Transmission Mode 2 - Accumulated average system throughput over given number of frames

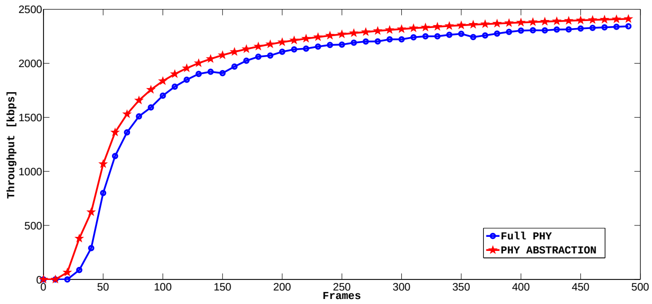

Fig. 9. LTE Transmission Mode 6 - Accumulated average system throughput over given number of frames

for diverse scenarios. The methodology was not only presented for SISO channels but also for MISO channels, employing STBC (Alamouti codes) and employing transmit precoding. Results from both of the simulators are shown for all transmission modes. It is very clear from the results that methodology is very accurate and indeed beneficial for the efficient system level evaluations.

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