Large Scale System Evaluations using PHY Abstraction for LTE with OpenAirInterface

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Abstract—**In this paper we present the complete methodology of expected effective SINR mapping (EESM) and mutual information effective SINR mapping (MIESM) based PHY abstraction for OpenAirInterface (OAI) LTE platform. The methodology consists of calibration of the ESM techniques using OAI link level simulator and then the validation of calibrated scheme on the OAI system level simulator. We present the methodologies for different transmission modes of LTE including transmission mode 1, 2 and 6 employing single-input single-output (SISO) channel, multiple-input single-output (MISO) channel with transmit precoding and transmit beamforming techniques respectively. We show that the calibration of PHY abstraction is a necessary step for these transmission modes and if properly calibrated then both of the ESM techniques can be used equivalently. Further we show with the help of results that the implemented PHY abstraction in the OAI system level simulator provides the speed in simulation time by a factor of 30 while providing the same accuracy as with the full PHY implementation. Since all the simulations are performed with OAI simulator which implements the LTE release 8.6 therefore our presented results provide portability for other LTE simulators as well.**

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. It was found with the help of profiling in OAI system level simulator that for any kind of simulation more than 75% of the total simulation time and resources were spent only on the modulation, demodulation, coding, decoding and the convolution of the channel with the signal at the physical layer. This is a huge overhead in terms of complexity and time duration of system level evaluations. Therefore, to reduce the complexity and duration of system level evaluations we need to have an interface which replaces the actual physical layer computations and provides the higher layers with necessary and accurate link quality metric, i.e., block error rate (BLER) or packet error rate (PER).

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.

A. *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

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- 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.

II. PHY Abstraction

PHY abstraction, also referred to 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 as shown in Figure 1 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. 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 [1] for system level evaluations and since then it has been extensively used for link quality modeling. In [2] it is shown that EESM is a suitable choice for 3GPP LTE wireless systems and it outperforms the other schemes. Further

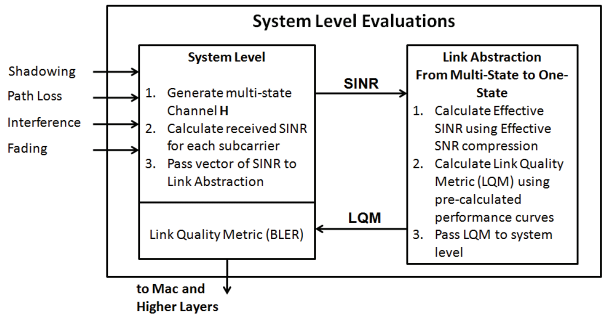

Fig. 1. Link Abstraction in System Performance Evaluation

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 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 [3] 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 [4] 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 [5] (Wireless World Initiative New Radio- WINNER) MIESM was selected as the link performance modeling methodology.

A. PHY Abstraction in OpenAnirInterface

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

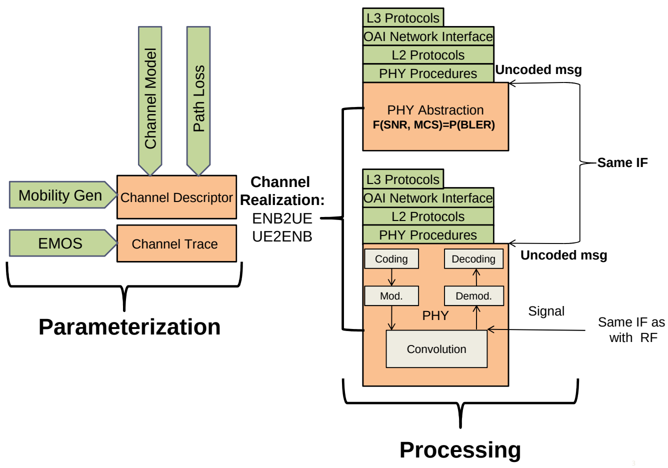

Fig. 2. PHY Abstraction in System Performance Evaluation in OpenAirInterface

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.

III. LTE Transmission Modes

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. For the transmission mode 5 the possible PHY abstraction schemes are described in [6]. Since LTE TM 1 represents a SISO system so $N_t = 1$ whereas TM 2 and 6 represent MISO systems with $N_t = 2$.

A. LTE Transmission Mode 1

Figure 3 shows the system model for LTE TM 1 where a single antenna eNodeB is communicationg with single antenna UEs. 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

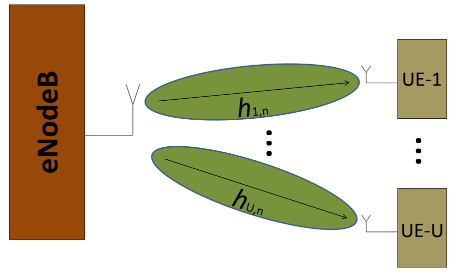

Fig. 3. SISO: system model with one singe antenna eNodeB and U single antenna UEs

independent and belong to discrete M-QAM constellations with variance $\sigma_u^2 = 1$. The received singal to noise ratio (SNR) at u-th UE on n-th resource element is given by

$$\gamma_{u,n} = \frac{|h_{u,n}|^2.\sigma_u^2}{N_0} = \frac{|h_{u,n}|^2}{N_0} \quad (1)$$

B. LTE Transmission Mode 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. Figure 4 shows the system model for LTE TM 2 where a dual antenna eNodeB is communicationg with single antenna UEs. We assume that the channel is i.i.d but

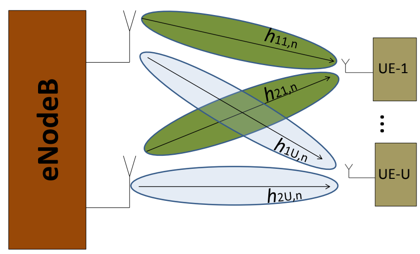

Fig. 4. Transmit Diversity: system model with a dual antenna eNodeB and U single antenna UEs

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

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

$$\mathbf{X}_{u,n} = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix}, \mathbf{h}_{u,n} = \begin{bmatrix} h_{1u,n} \\ h_{2u,n} \end{bmatrix} \text{ and } \mathbf{z}_{u,n} = \begin{bmatrix} z_1 \\ z_2 \end{bmatrix}$$

where $\frac{1}{\sqrt{2}}$ is the power normalization factor for both antennas, $\mathbf{h}_{u,n} \in \mathbb{C}^{2\times 1}$ 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. On the receiver joint processing for the two symbols is applied and the received SNR at u-th UE on n-th resource element can be calculated as,

$$\gamma_{u,n} = \frac{|h_{1u,n}|^2 + |h_{2u,n}|^2}{2.N_0} \tag{2}$$

C. LTE Transmission Mode 6

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. Figure 5 shows the system model for LTE TM 6 where a dual antenna eNodeB performs transmit precoding towards single antenna UEs. The received

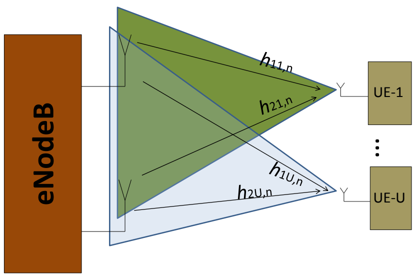

Fig. 5. Transmit Precoding: system model with a dual antenna eNodeB and U single antenna UEs

signal for LTE TM 6 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 $\mathbf{h}_{u,n}^{\dagger}\mathbf{p}_{u,n}$ is the effective precoded channel from eNodeB to the 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,

$$\mathbf{p}_{u,n} = \frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}, \frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}, \frac{1}{\sqrt{2}}\begin{bmatrix}1\\\mathrm{j}\end{bmatrix}, \frac{1}{\sqrt{2}}\begin{bmatrix}1\\-\mathrm{j}\end{bmatrix}$$

The received SNR at u-th UE on n-th resource element is given by

$$\gamma_{u,n} = \frac{|h_{1u,n} + qh_{2u,n}|^2}{2.N_0} \tag{3}$$

where $q \in \{\pm 1, \pm j\}$.

IV. Abstraction Methods

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. For this purpose 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).

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

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[1], i.e.,

$$I(\gamma_n) = 1 - \exp(-\gamma_n) \tag{5}$$

$$\gamma_{\text{eff}}(\beta_1, \beta_2) = -\beta_1 \ln\left[\frac{1}{N}\sum_{n=1}^{N}\exp\left(-\frac{\gamma_n}{\beta_2}\right)\right] \tag{6}$$

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.

$$I_{M_1}(\gamma_j) = \log M_1 - \frac{1}{M_1}\sum_{x_1\in\chi_1}\mathcal{E}_{z_1}\log\frac{\sum_{x_1'\in\chi_1}\exp\left[-\left|\gamma_j\left(x_1 - x_1'\right) + z_1\right|^2\right]}{\exp\left[-|z_1|^2\right]} \tag{7}$$

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

For the PHY abstraction $\gamma_{\text{eff}}(\beta_1, \beta_2)$ can be calculated using (4), the respective information function for EESM and MIESM, and the received SINR expressions from (1), (2) and (3) for each of the LTE transmission modes. This γ_{eff} then can be used to obtain the BLER from the previously calculated AWGN performance curves corresponding to the specific MCS, i.e.,

$$\text{BLER}(\boldsymbol{\gamma}, \text{MCS}) \simeq \text{BLER}_{\text{A}}(\gamma_{\text{eff}}(\beta_1, \beta_2), \text{MCS}) \tag{8}$$

Where $\boldsymbol{\gamma}$ represents the $N \times 1$ vector of γ_n and BLER_{A} represents the AWGN block error rate obtained for specific MCS.

V. Link Level Calibration

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 and used both ESM methods for the calculation of $\gamma_{\text{eff}}(\beta_1, \beta_2)$. For this paper we used ideal channel estimation with 8-tap Rayleigh channel model with

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

TABLE I
SIMULATION PARAMETERS FOR LINK LEVEL SIMULATOR

OpenAirInterface Link Level Parameters	
Transmission Mode	1, 2, 6
Transmission Bandwidth	5 MHz
FFT Size	512
Subcarrier Spacing	15 KHz
Useful Subcarriers	300
Subframe Length	1 ms
Cyclic Prefix	Normal
Physical Resource Blocks	25
Channel	8-tap Rayleigh Channel Model
Delay Spread	1e-6 second
Channel Estimation	Ideal
Decoder	Max-log Map
MCS	0 - 22

the delay spread of 1e-6 seconds. Further parameters for the link level simulator are given in Table I. For each of the transmission mode and each of the MCS, we performed link level simulations for a large number of 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 $\text{BLER}_{\text{m,MCS}}$ 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

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

$$\text{MSE} = \sum_{i=1}^{N_{ch}} \left|\text{BLER}_\text{A}\left(\gamma_\text{eff}\left(\beta_1, \beta_2\right), \text{MCS}\right) - \text{BLER}_{\text{m,MCS}}\right|^2$$

where MSE is the mean squared error, N_{ch} is the number of different channel realizations, $\text{BLER}_\text{A}\left(\gamma_\text{eff}\left(\beta_1, \beta_2\right), \text{MCS}\right)$ is the predicted block error rate from the respective AWGN curve and from the $\gamma_\text{eff}\left(\beta_1, \beta_2\right)$ calculated using (4) for both of the ESM methods, and $\text{BLER}_{\text{m,MCS}}$ is the error rate from the N_{ch} channel realizations. To obtain the $\text{BLER}_\text{A}\left(\gamma_\text{eff}\left(\beta_1, \beta_2\right), \text{MCS}\right)$ 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 6.

A. Results

After calibration we applied both of the ESM PHY abstraction techniques on the saved outputs of the link level simulations. In the following we provide the tables where we present the calibration factors with minimum MSE for both of the ESM PHY abstraction techniques and it can be seen that the MSE is very low for both techniques. Table II, III and IV present β_1, β_2 and MSE for both EESM and MIESM for MCS 0-22 for transmission mode 1, 2 and 6 respectively. It can be

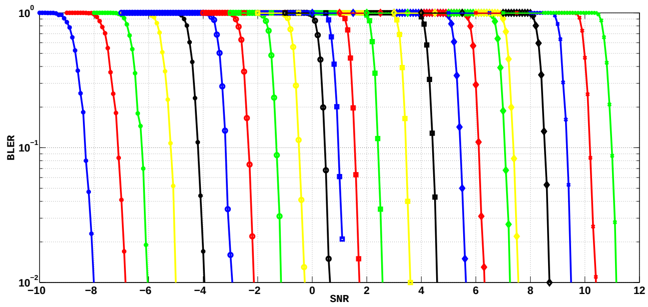

Fig. 6. AWGN Link Performance Curves in LTE with 5 MHz Bandwidth for MCS 0 - 22

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

MCS	EESM			MIESM		
	β_1	β_2	**MSE**	β_1	β_2	**MSE**
0	2.51867	2.49808	0.00391	1.11876	1.12934	0.00498
1	0.48797	0.48677	0.01437	0.37201	0.37072	0.01334
2	0.51811	0.51144	0.00526	0.37550	0.37219	0.00509
3	1.15845	1.14284	0.00891	0.94532	0.93101	0.00862
4	0.79600	0.79522	0.00578	0.57989	0.58077	0.00568
5	0.77935	0.77683	0.00493	0.52590	0.52793	0.00475
6	0.80905	0.79431	0.00708	0.54849	0.54037	0.00685
7	0.80876	0.79535	0.00842	0.53399	0.52787	0.00750
8	0.80563	0.81064	0.00919	0.51646	0.52099	0.00933
9	0.84083	0.82789	0.00576	0.52998	0.52262	0.00483
10	1.91969	1.85813	0.01039	0.64432	0.63280	0.01114
11	1.95414	1.90448	0.00708	0.59618	0.58269	0.00781
12	2.35630	2.26533	0.01159	0.48836	0.48043	0.00911
13	2.48046	2.41211	0.01111	0.49270	0.48302	0.01071
14	2.41703	2.37478	0.01093	0.36865	0.36376	0.00720
15	2.99274	2.92132	0.01046	0.46138	0.45064	0.00684
16	2.84205	2.87155	0.02203	0.40809	0.41069	0.03005
17	5.27602	5.02621	0.03266	0.26393	0.25466	0.01751
18	5.75658	5.42143	0.03246	0.29350	0.27973	0.01616
19	6.48658	6.08509	0.03809	0.25203	0.24131	0.03036
20	7.79768	7.18738	0.02389	0.37087	0.33508	0.02685
21	7.78316	7.46862	0.06827	0.29065	0.27502	0.07025
22	7.49917	7.51829	0.07799	0.26116	0.25681	0.11458

seen that the optimal calibration factors for the MIESM and EESM are very much different than the unity. Therefore even for the case of MIESM, calibration is required to reach a good level of accuracy. Further these results show that if both of the ESM methods are calibrated correctly then the performance of both ESM methods becomes almost the same. Therefore one can use any one of the two techniques in the system level simulator with proper calibration.

VI. SYSTEM LEVEL VALIDATION

Link level results show that our approach for the ESM PHY abstraction is very much accurate and any of the two methods can be used in system level simulators. Therefore we decided to implement EESM in the OAI system level simulator [7] for large scale evaluations. This system level simulator implements the full protocol stack for different transmission modes of LTE. We wanted to show that how

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

MCS	EESM			MIESM		
	β_1	β_2	**MSE**	β_1	β_2	**MSE**
0	0.51505	0.51133	0.00469	0.71378	0.70281	0.00623
2	0.72291	0.71876	0.00205	0.55335	0.55028	0.00204
3	0.69201	0.68623	0.00354	0.48285	0.48147	0.00344
4	0.72305	0.71997	0.00282	0.49984	0.50057	0.00250
5	0.69175	0.68011	0.00263	0.49064	0.48318	0.00243
6	0.74296	0.71927	0.00433	0.49418	0.48104	0.00383
7	0.79333	0.76209	0.00280	0.53226	0.51240	0.00305
8	0.79476	0.76746	0.00326	0.51416	0.49643	0.00258
9	0.77145	0.72608	0.00322	0.47562	0.44854	0.00286
10	1.79586	1.69821	0.00606	0.58539	0.55756	0.00413
11	1.63912	1.57082	0.00369	0.41666	0.39708	0.00408
12	1.90221	1.82649	0.00694	0.44454	0.42387	0.00691
13	2.31685	2.17287	0.00871	0.39421	0.37011	0.00785
14	2.66179	2.44757	0.00491	0.37893	0.34935	0.00330
15	2.29127	2.17064	0.02918	0.27565	0.26303	0.03556
16	3.11592	2.86310	0.00963	0.44559	0.40529	0.00740
17	4.46069	4.08881	0.01218	0.16501	0.15051	0.01651
18	5.21514	4.62933	0.02739	0.22538	0.20013	0.04562
19	5.96413	5.21403	0.02564	0.23530	0.20244	0.04945
20	6.46220	5.54003	0.07693	0.20975	0.17879	0.07800
21	7.60083	6.46778	0.06793	0.25174	0.21238	0.07145
22	9.87314	8.17512	0.04159	0.32418	0.26681	0.04350

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

MCS	EESM			MIESM		
	β_1	β_2	**MSE**	β_1	β_2	**MSE**
0	0.43114	0.42671	0.00391	0.71458	0.69798	0.00669
1	0.57761	0.56792	0.00349	0.47890	0.46943	0.00347
2	0.69824	0.69631	0.00221	0.53920	0.53792	0.00227
3	0.70350	0.69631	0.00364	0.55563	0.54833	0.00386
4	0.72077	0.71818	0.00285	0.49747	0.49825	0.00253
5	0.71127	0.69330	0.00147	0.48994	0.47943	0.00173
6	0.70513	0.68993	0.00390	0.46907	0.46111	0.00394
7	0.80003	0.76490	0.00381	0.52612	0.50511	0.00321
8	0.81582	0.77642	0.00311	0.52780	0.50203	0.00284
9	0.78684	0.74239	0.00354	0.49624	0.46719	0.00402
10	1.81199	1.73499	0.00551	0.45132	0.44134	0.01067
11	1.80174	1.72851	0.00372	0.41129	0.39574	0.00192
12	2.34708	2.19196	0.00706	0.46224	0.43891	0.00359
13	2.59607	2.41612	0.00578	0.46088	0.43443	0.00632
14	2.57389	2.38144	0.00385	0.39457	0.36445	0.00351
15	2.81933	2.59327	0.00866	0.39905	0.36611	0.00594
16	2.70396	2.53965	0.02087	0.35318	0.33006	0.02625
17	4.93805	4.43685	0.01588	0.24389	0.21788	0.01424
18	4.84900	4.46593	0.01656	0.18978	0.17297	0.01656
19	6.80857	5.92575	0.01480	0.29295	0.25357	0.01200
20	7.04470	6.27926	0.04026	0.27118	0.23895	0.05122
21	9.33852	8.03885	0.01717	0.33666	0.28843	0.02017
22	9.96321	8.28751	0.06238	0.35912	0.29355	0.05003

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 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. The important point for the system level simulations are,

- Abstraction is only implemented for the downlink shared channel (DLSCH) and there is no abstraction for uplink (UL) and Control channels.
- Scheduler gives most of the resources to the user with better fedback CQI.
- Full Buffer traffic is produced and the eNodeB can select between mcs 0-22 for the downlink (DL) communication.

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

TABLE V
SIMULATION TIMES DIFFERENT TRANSMISSION MODES

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

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 be even significant while maintaining the realism of evaluations.

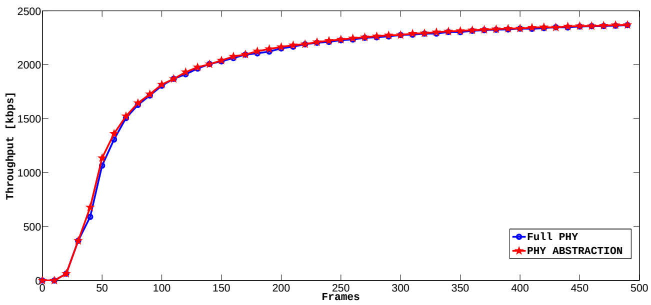

Fig. 7. LTE Transmission Mode 1 - Accumulated average system throughput over given number of frames

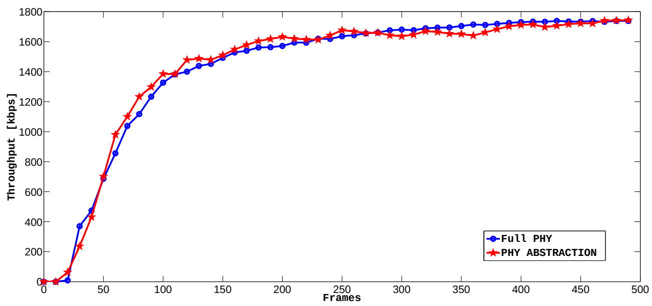

Fig. 8. LTE Transmission Mode 2 - Accumulated average system throughput over given number of frames

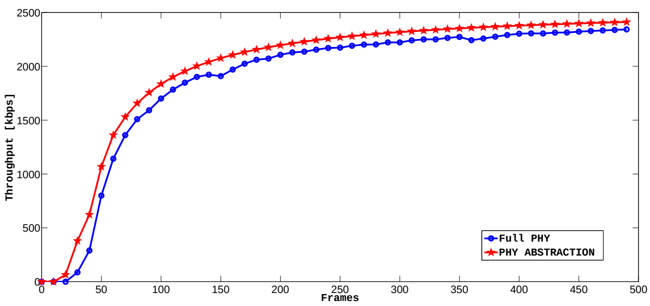

Fig. 9. LTE Transmission Mode 6 - Accumulated average system throughput over given number of frames

VII. 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. Also it was shown that with proper calibration both EESM and MIESM perform similarly and thus both can be used equivalently. 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 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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