Link Abstraction for Multi-User MIMO in LTE using Interference-Aware Receiver

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***Abstract*—Most of the recent wireless communication systems are interference limited rather than noise limited. In the case of a very strong interferer the conventional assumption of the interference as Gaussian is extremely suboptimal. However optimal (capacity achieving) receivers utilize some prior knowledge about the interference to reach optimality. The link abstraction for such receiver structures is not studied well. We investigate how the conventional mutual information based link abstraction technique can be extended for the accurate and efficient link performance modeling for low complexity optimal receivers. So, in this paper we propose a mutual information based link abstraction methodology of an optimal, low complexity interference aware receiver for multi-user MIMO in the frame work of LTE. For the sake of comparison we performed abstraction of interference aware receiver with Exponential Effective SINR Mapping (EESM) method as well. We show with the help of results that our proposed method outperforms the EESM and provides the system level with more accurate link quality metric.**

I. Introduction

Baseline specifications of 3GPP's Long Term Evolution (LTE) system offers at least 100Mbits/s of data rate at the downlink and 50Mbits/s at the uplink. These are the data rates which were only possible on the wired networks only a decade ago. But today, LTE is being deployed in some parts of the world making it possible to obtain such high data rates even for wireless cellular communications. The applications of high speed wireless cellular communications are in almost all fields of life, i.e., medical, defense, business and not to forget the social life. Considering the combination of smart phones, tablets, netbooks, online social media and cloud computing, the need for higher data rates is on the rise more than ever. That is why the latest release of LTE named as LTE-Advanced (LTE-A) is targeting the data rates of 1 Gbits/s on the downlink and 500 Mbits/s on the uplink.

The key technology in LTE and LTE-A is the use of multiple antennas at the transmitter and the receiver. The gains offered by the use of multiple antennas in LTE can come from spatial multiplexing, spatial diversity and/or precoding. MIMO systems generally fall into two categories, single-user (SU) MIMO and multi-user (MU) MIMO. As compared to SU MIMO, MU-MIMO has lots of potential [1] and can be highly spectral efficient by serving more than one user for the same time and frequency resource. The gains offered by MU-MIMO on the single communication link do not necessarily represent the same gains when it is deployed in a huge system. Therefore the system level evaluations are necessary to be performed before its deployment. The realistic evaluations should not only account for the benefits of more sophisticated techniques but also should be able to reflect the effects of different kind of interferences in the network.

However, system level evaluations 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 are the bottle neck in these evaluations. Therefore, to reduce the complexity and duration of system level simulations, we need to have an accurate link abstraction model 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).

This paper presents a method of extending the link abstraction for interference limited systems where the low complexity optimal receivers are used. The low complexity receivers normally use some prior knowledge about either interference itself or about its structure to reach the optimality. As an example we perform the link abstraction for MU-MIMO in LTE release 8, where the link abstraction predicts the performance of a low complexity interference aware (IA) receiver.

Rest of the paper is organized as follows: Section II presents link abstraction and state of the art for link abstraction. Section III presents an overview of MU-MIMO in LTE release 8 and mutual information under interference for MU-MIMO. In Section IV the link abstraction for MU-MIMO is described in detail. Then, Section V presents results of the proposed abstraction technique and compares it with the standard EESM results. Finally, Section VI presents the conclusion and possible future work directions.

II. Link Abstraction

The purpose of link abstraction is to provide an accurate mapping between the link level and system level simulator in terms of the link quality measure. For MIMO-OFDM systems,

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the process of link abstraction can be defined as, the process which predicts the link quality (in terms of BLER) for a specific channel realization across all of the OFDM subcarriers and spatial layers by taking into account the power and resource allocation, modulation and coding scheme (MCS), and other parameters that can influence the link performance. These other parameters mainly include channel characteristics, i.e., path loss, shadowing, fading and interference. The use of link abstraction in system evaluations is explained in Figure 1.

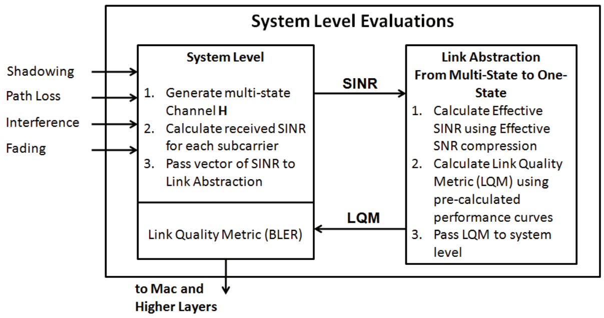

Fig. 1. Link Abstraction in System Performance Evaluation

After the link quality metric is sent to the MAC layer, a random number between 0 and 1 is generated. This number is compared with the BLER for taking the decision on the successful or unsuccessful transmission. So, in this form link abstraction is an extremely valuable low complexity tool for efficient large scale system evaluations. Because it provides the system simulator with the necessary link quality measure without actually having to code and decode the packets. Moreover, it can also be used for fast resource scheduling, fast link adaptation using adaptive power control, and adaptive modulation and coding (AMC).

However performance evaluation of highly frequency selective channels is not that straight forward and many link abstraction techniques have been proposed in the literature for these 'multi-state' channels. [2][3][4] discuss the possible link performance models which are capable of capturing the effects of the multi-state channels. Exponential effective SINR mapping (EESM) was first introduced in system level evaluations in [2] and since then onwards have been extensively used for link quality modeling. In [5], it is shown that EESM is a suitable choice for 3GPP LTE wireless systems and it performs better than other link quality schemes but mutual-information based methods were not considered for the comparison. They also showed through simulations that training of link abstraction is independent of the used channel model. 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 for single antenna systems mutual-information based effective SINR mapping (MIESM) performs better in both complexity and performance than all other approaches. They also showed that for multi-antenna system MIESM is able to describe the characteristics of modulation and coding schemes in a much better way than other schemes. In [6] authors have introduced one more calibration factor for EESM and shown that it speeds up the abstraction process.

In [7] authors have studied the abstraction for generalized spatial channel model (SCM) and in [8], abstraction for OFDM based mobile networks is discussed. 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. They showed the superiority of MIESM over EESM using this approach as well. This result was strengthened by [9] (Wireless World Initiative New Radio-WINNER) and MIESM was chosen to be the link performance modeling methodology. An interesting result is shown in [10] which states that the training for the link quality model of MIMO systems should not be done by using SISO systems. They strengthen their point by showing results for 2x2 open loop MIMO system using both EESM and MIESM and they have also shown that MIESM performs better than EESM.

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 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, and then this value is used to read the equivalent BLER from the AWGN performance curves for a particular modulation and code scheme (MCS).

$$\gamma_{eff} = \delta_1 I^{-1}\left[\frac{1}{J}\sum_{j=1}^{J} I\left(\frac{\gamma_j}{\delta_2}\right)\right] \tag{1}$$

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

Where J is the number of channel symbols in a codeword and $I(\gamma_j)$ 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. δ_1 and δ_2 are called calibration factors and they are there to compensate for different modulation orders and code rates.

For the EESM the mapping function $I(\gamma_j)$ is calculated using Chernoff Union bound of error probabilities[2], i.e.,

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

$$\gamma_{eff} = -\beta \ln\left[\frac{1}{J}\sum_{j=1}^{J} \exp\left(-\frac{\gamma_j}{\beta}\right)\right] \tag{4}$$

Normally for EESM $\delta_1 = \delta_2 = \beta$ and it needs to be adjusted for each MCS. Whereas for the MI-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 $z_1 \in \mathcal{CN}(0,1)$.
The accuracy of link abstraction is very critical for the correct system evaluation and it is shown in [4][3][10] that MI-based link abstraction techniques are more accurate than EESM. So we shall use MI-based link abstraction for MU-MIMO in LTE.

III. Multi-User MIMO in LTE using IA Receiver

LTE Release 8 was standardized generally to benefit from SU-MIMO, so the support for MU-MIMO (LTE transmission mode 5) was added only at a very basic level in it. In MU-MIMO, eNodeB schedules two or more users during the same time and frequency resource, so ideally it requires full channel state information at transmitter (CSIT) in order to provide independent parallel channels from cross coupled channels (i.e., eliminating multi-user interference). But in LTE Release 8 the rank indicator (RI) and precoding matrix indicator (PMI) feedback are the same as for SU-MIMO rank 1 and it only contains four precoders, $\mathbf{p} = [1 \quad q]^T, \quad q \in \{\pm 1, \pm j\}$, which are extremely low resolution needing merely 2 (for 2 antenna ports) to 4 (for 4 antenna ports) bits of feedback from the users. On top of this low resolution precoding comes the overhead of quantization and feedback delays. This significantly degrades the performance of MU-MIMO in LTE Release 8 even after using the optimal scheduling for selected users. A way forward to achieve the gains of MU-MIMO in LTE Release 8 is to employ IA receiver, as was shown in [11] and [12]. Therefore, in this paper IA receiver is used for MU-MIMO.

a) Mutual information under interference: The detailed mutual information expressions for a MU MIMO system employing such a receiver are given in [11] which will subsequently be used in our abstraction model. We assume LTE baseline configuration, where a dual-antenna eNodeB communicates with 2 single-antenna UEs. The received signal at the desired user (say UE-1) on n-th resource element is given by

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

where $\mathbf{h}_{1,n}^{\dagger} \in \mathbb{C}^{2\times 1}$ symbolizes the MISO channel from the eNodeB to UE-1, $\mathbf{p}_{k,n}$ is the precoder requested by k-th UE and $z_{1,n}$ is ZMCSCG white noise of variance N_0 at UE-1. Complex symbols $x_{1,n}$ and $x_{2,n}$are assumed to be independent and of variances σ_1^2 and σ_2^2, respectively. These symbols belong to discrete QAM constellations, i.e. $\chi_{1,n}$ and $\chi_{2,n}$ respectively. The dependency on the resource element index can be ignored, since the processing is assumed to be performed on a resource element basis for each received OFDM symbol. Moreover we denote the effective channels as $\alpha_1 = \mathbf{h}_1^{\dagger}\mathbf{p}_1$ and $\zeta_2 = \mathbf{h}_1^{\dagger}\mathbf{p}_2$. The mutual information expression for desired user in such a system is given by (6). In [11] the authors have shown that optimal low complexity IA receiver can actually be implemented achieving (6).

IV. Abstraction for Multi-User MIMO

In the following an extension of the MI-based abstraction of [4] is presented for the link abstraction of IA receivers.

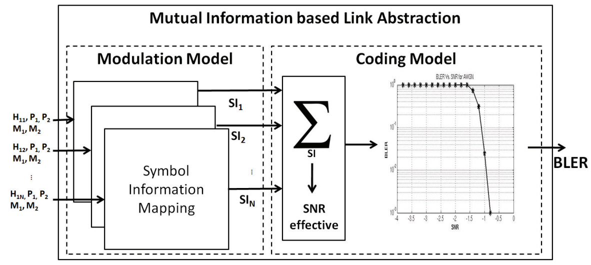

Fig. 2. Mutual information based abstraction model

The abstraction model consists of two blocks, modulation model and coding model, as is shown in Figure 2, details of which are given in the next subsections. Our approach is different from [4] because the inputs for link abstraction can not only be SINR values for each subcarrier but also the channel of desired user, precoder and constellation of desired and interfering user. So our approach is able to take interference as an important parameter and exploit it unlike [4] where interference is included in the noise. Which means that in our approach modulation model can be configured for both multi-user detection and single-user detection.

A. Modulation Model

Modulation model as shown in Figure 2 provides us with the symbol information (SI) in terms of maximum channel capacity for each of the subcarrier. It was found numerically that after the optimal scheduling at eNodeB (i.e., selecting only UEs who have asked for the opposite precoders) the mutual information of (6) only depends on the magnitudes of the $\alpha_{1,j}$ and $\zeta_{2,j}$ so in this case SI can be calculated using (6), i.e.,

$$SI\left(|\alpha_{1,j}|, |\zeta_{2,j}|, M_{1,j}, M_{2,j}\right) = I\left(Y; X_1 | (|\alpha_1|, |\zeta_2|)\right) \tag{7}$$

Since no analytical solution for symbol information mapping is present in the literature so this should be calculated numerically and saved as look-up tables (LUT). These tables can be generated by Monte-Carlo simulations of (6) over a wide range of noise and channel realizations. For each channel realization a random set of $|\alpha_1|$, $|\zeta_2|$ and mutual information is obtained. For all of the combinations of non-simulated points one can use linear interpolation. As an example an interpolated graph for the SNR of 10 dB is shown in Figure 3 where on the x-axis is the signal strength, on y-axis is the interference strength and on z-axis is the mutual information.

B. Coding Model

The coding model corresponds to the encoding and decoding of the codeword and predicts the performance of whole codeword. But to do that coding model first performs the

$$I(Y;X_1|\alpha_1,\zeta_2) = \log M_1 - \frac{1}{M_1 M_2 N_z N_h}\sum_{x_1}\sum_{x_2}\sum_{\mathbf{h}_1^\dagger}^{N_h}\sum_{z_1}^{N_z}\log\frac{\sum_{x_1'}\sum_{x_2'}\exp\left[-\frac{1}{N_0}\left|\alpha_1 x_1+\zeta_2 x_2+z_1-\alpha_1 x_1'-\zeta_2 x_2'\right|^2\right]}{\sum_{x_2''}\exp\left[-\frac{1}{N_0}\left|\zeta_2 x_2+z_1-\zeta_2 x_2''\right|^2\right]} \quad (6)$$

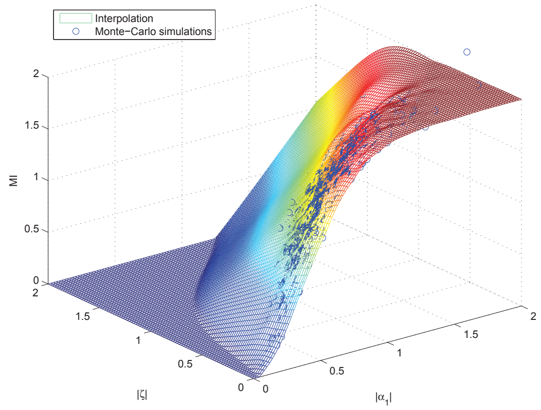

Fig. 3. MI for SNR of 10 dB

compression on the multi-state channel to convert it into one-state channel and then reads the corresponding AWGN performance curve providing with the link quality measure. The output of modulation model is a vector holding symbol informations for all of the subcarriers of a codeword. The first thing which coding model calculates is the received coded bit information (RBI) for the desired user among J subcarriers,

$$RBI = \sum_{j=1}^{J}\frac{SI\left(|\alpha_{1,j}|,|\zeta_{2,j}|,M_{1,j},M_{2,j}\right)}{\beta} \quad (8)$$

Where the first index in modulation order $M_{i,j}$ represents the user and second index represents the subcarrier. β is an adjustment factor which compensates for the coding losses. RBI is then normalized by the number of total coded bits to the received bit information rate (RBIR). Lets call this as RBIR_{abs} where abs stands for abstraction.

$$RBIR_{abs} = \frac{RBI}{\sum_{j=1}^{J} M_{1,j}} \quad (9)$$

This RBIR_{abs} is a compressed value which will now be used for calculating the γ_{eff}.
To obtain γ_{eff} from RBIR_{abs} we need an inverse mapping funchtion I^{-1} as is required in (1). This inveverse mapping function is based on the normalized mutual information, i.e.,

$$RBIR = \frac{I_{M_1}(\gamma)}{M_1} \quad (10)$$

Where I_{M_1} comes from (5) and is a function of γ which makes resulting RBIR also a function of γ. Using this realtionship for different constellations, RBIR Vs. SINR tables can be generated and stored in the form of LUTs as is shown in Figure 4. Finally with the help of these tables and RBIR_{abs} we can get γ_{eff} which is then used to obtain BLER (link quality measure) from the equivalent AWGN performance curve for a specific MCS.

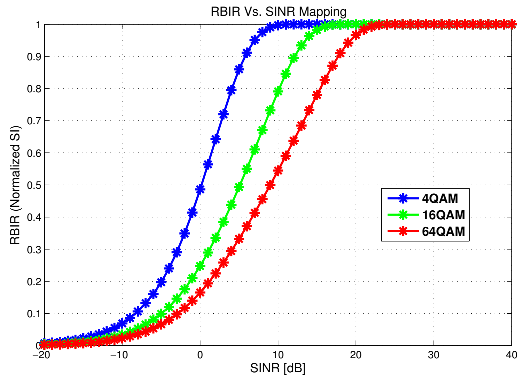

Fig. 4. RBIR Vs. SINR Mapping

C. Calibration of Adjustment Factor

Calibration of adjustment factor (β) is very important for the accurate mapping of multi-state channels into one-state channel. We performed calibration through an iterative procedure which requires a starting point (normally initial $\beta = 1$) then it is chosen such that

$$\hat{\beta} = \underset{\beta}{\operatorname{argmin}}\left[\sum_{i=1}^{N_{ch}}\left|BLER_{pred,mcs}(\beta) - BLER_{meas,mcs}\right|^2\right]$$

where N_{ch} is the number of different channel realizations, $BLER_{pred,mcs}$ is the predicted block error rate from the respective AWGN curve and $BLER_{meas,mcs}$ is the error rate from N_{sim} channel realizations. These AWGN curves are pre-calculated for all MCS of LTE and stored in the form of LUTs.

V. Results

In order to test the proposed MU-MIMO link abstraction for IA receivers, Eurecom's OpenAirInterface[1] link-level simulator was used which implements 3GPP LTE Release 8.6 physical layer [13], [14], [15] with 5 MHz bandwidth and 25 physical resource blocks (PRB). The simulations were carried for the system there was a dual antenna eNodeB and two single-antenna UEs using 8-tap Rayleigh channel with real channel estimation. In every simulation $N_{ch} = 100$ and for every channel realization there were 10000 noise realizations. The constellation of required user and interfering user was the same. From these simulations the error rates for each channel realization and other necessary parameters for link

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

abstraction were saved. With these saved data abstraction was performed and results of both abstraction techniques for LTE mcs 9 (4QAM) and mcs 16 (16QAM) are shown in Figure 5 and 6, respectively.

The solid lines represent the AWGN curves where as the red diamonds and blue stars show the effective SINR points which are mapped on the AWGN reference curves. It is clear from the Figure 6 that the proposed MI-based link abstraction is very accurate and maps the instantaneous channel realizations onto the corresponding AWGN curve very well. On the other hand EESM mapping has failed to effectively do so, as is shown in Figure 5, and one can see that the spread of the points around the AWGN curve is very high giving rise in the mean squared error.

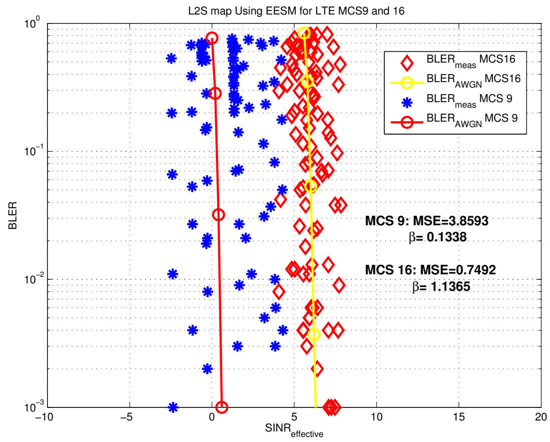

Fig. 5. MU-MIMO abstraction (EESM) for LTE MCS 9 and 16 using 8-tap Rayleigh Channel Model

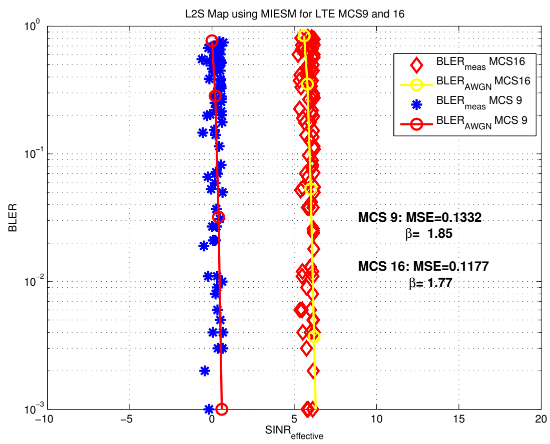

Fig. 6. MU-MIMO abstraction (MI-based) for LTE MCS 9 and 16 using 8-tap Rayleigh Channel Model

VI. Concluding Remarks

This paper presented a link abstraction technique for interference limited systems. As an example it was applied towards MU-MIMO in LTE Release 8 for the specific case of IA receiver and compared with standard EESM approach. The results showed that accuracy of the proposed method is far better than EESM and this kind of approach can be a good candidate for accurate and efficient system evaluations for the interference limited systems. In the future work this link abstraction for higher modulation orders, i.e., 64QAM is to be investigated and also it is planned to investigate the cases where the interference comes from the different constellations as compared to that of the desired user.

References

[1] D. Gesbert, M. Kountouris, R. W. Heath, Jr., C. B. Chae, and T. Sälzer, "From single user to multiuser communications: Shifting the MIMO paradigm," *IEEE Signal Process. Mag.*, vol. 24, no. 5, pp. 36–46, Sep. 2007.

[2] Nortel Networks, "OFDM Exponential Effective SIR Mapping Validation, EESM Simulation Results," 3GPP, Tech. Rep. R1-040089, Jan. 2004.

[3] K. Brueninghaus, D. Astely, T. Salzer, S. Visuri, A. Alexiou, S. Karger, and G. A. Seraji, "Link Performance Models for System Level Simulations of Broadband Radio Access Systems," in *16th Annual IEEE International Symposium on Persoanl, Indoor and Mobile Radio Communications Germany*, 2005, pp. 2306–2311.

[4] L. Wan, S. Tsai, and M. Almgren, "A Fading-Insensitive Performance Metric for a Unified Link Quality Model," in *Wireless Communications and Networking Conference, 2006. WCNC 2006. IEEE*, vol. 4, 2006, pp. 2110 –2114.

[5] R. B. Santos, W. C. Freitas Jr., E. M. G. Stancanelli, and F. R. P. Cavalcanti, "Link-to-System Level Interface Solutions in Multistate Channels for 3GPP LTE Wireless System," *XXV Simposio Brasileiro de Telecomunicacoes*, 2007.

[6] A. Oborina and M. Moisiot, "Speed Up of Effective SINR Mapping Calculations for System Level Simulations," *IET Seminar Digests*, pp. 43–43, 2007.

[7] A. Rodriguez-Herrera, S. McBeath, D. Pinckley, and D. Reed, "Link-to-System Mapping Techniques using a Spatial Channel Model," in *IEEE 62nd Vehicular Technology Conference, 2005. VTC-2005-Fall.*, vol. 3, sept., 2005, pp. 1868 – 1871.

[8] E. Tuomaala and H. Wang, "Effective SINR Approach of Link to System Mapping in OFDM/Multi-Carrier Mobile Network," in *2nd International Conference on Mobile Technology Applications and Systems*, nov. 2005, pp. 5 pp. –5.

[9] M. Döttling, "Assessment of Advanced Beamforming and MIMO Technologies," European Commission, Project Deliverable IST-WINNER (2003-507581), 2005.

[10] J. Olmos, S. Ruiz, M. Garcia-Lozano, and D. Martin-Sacristán, "Link Abstraction Models Based on Mutual Information for LTE Downlink," *COST 2100 TD(10)11052*, pp. 1–18, 2010.

[11] R. Ghaffar and R. Knopp, "Interference-Aware Receiver Structure for Multi-User MIMO and LTE," *EURASIP Journal on Wireless Communications and Networking 2011*, 2011.

[12] I. Latif, F. Kaltenberger, R. Ghaffar, R. Knopp, D. Nussbaum, H. Callewaert, and G. Scot, "Performance of LTE in Rural Areas - Benefits of Opportunistic Multi-User MIMO," in *PIMRC 2011, 22nd Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, September 11-14, 2011, Toronto, Canada*, 09 2011.

[13] 3GPP, "Physical channels and modulation," 3GPP, Technical Specification 36.211-V8.6.0, Sep. 2009.

[14] ——, "Multiplexing and channel coding," 3GPP, Technical Specification 36.212-V8.6.0, Sep. 2009.

[15] ——, "Physical layer procedures," 3GPP, Technical Specification 36.213-V8.6.0, Sep. 2009.