A Channel Feedback Model with Robust SINR Prediction for LTE Systems

Mingjian Ni, Xiang Xu, and Rudolf Mathar

Institute for Theoretical Information Technology, RWTH Aachen University
Aachen, Germany 52074
Email: {ni, xu, mathar}@ti.rwth-aachen.de

***Abstract*—In Long Term Evolution (LTE) systems, user equipment (UE) provides channel state information (CSI) to base station in terms of Channel Quality Indicator (CQI) feedback. However, in the conventional feedback model, Signal to Interference plus Noise Ratio (SINR) is assumed to be constant over a certain period. This assumption is generally not true, since wireless channels change over time. In this paper, a channel feedback model with robust SINR prediction is presented. The CQI difference statistics are also taken into consideration in the proposed channel feedback model. The simulation results show that the proposed model improves the accuracy of channel feedback information by using extrapolation when UE moves at low speed. Thus, no second-order SINR statistics are required as a-priori information.**

***Index Terms*—LTE; channel feedback; CQI; SINR prediction**

I. Introduction

LTE systems apply Adaptive Modulation and Coding (AMC) to maximize the throughput in varying channel environment [1] [2]. AMC can adjust the modulation order and coding rate based on the feedback CSI, which is specified in terms of a 4-bit CQI. In the uplink, each UE reports appropriate CQI to the base station, or eNodeB in LTE terms. With the reported CQI, eNodeB can achieve a block error rate (BLER) lower than 10% in the downlink transmission [3]. Therefore, CQI plays a key role in LTE systems.

According to the 3GPP specification [3], UE periodically reports CQI of the current channel after a duration of k subframes, each corresponding to one millisecond. And k is a value not less than 4. This CQI feedback delay is caused by CQI measurement at the UE side, CQI feedback and CQI processing at the eNodeB side [4]. As a result, even if the CQI can be derived precisely and transmitted correctly, at the eNodeB side, it could only reflect the CSI k ms earlier. In k ms, the channel state can change dramatically and the feedback CQI may not reflect the current CSI correctly. Overly optimistic CQI could result in a BLER larger than 10%, thus extra retransmission may be necessary. And pessimistic CQI leads to lower modulation order and more redundant parity check bits. In both cases, the throughput decreases.

The eNodeB can perform prediction based on the received CQIs. However, the 4-bit CQI is just an integer ranging from 0 to 15. Even though CQI could directly reflect CSI, the highly quantized CQI would cause a coarse prediction.

The contribution of our work is to perform the prediction at the UE side in order to achieve better performance. In our work, the CQI report based on SINR prediction shows smaller error than the conventional CQI feedback scheme without prediction, in case that UE moves at low speed.

The variation of SINR value is influenced by many factors including fading channel, interference and thermal noise. To the authors' best knowledge, there is no simple model for SINR prediction over fast fading channel. Therefore, the proposed SINR prediction technique is based on extrapolation. The second-order statistics of SINR are not required.

The remainder of this paper is organized as follows. In Section II, the channel feedback model with robust SINR prediction is explained. The CQI difference statistics are introduced in Section III. The simulation results are presented and analyzed in Section IV. Finally, conclusions are given in Section V.

II. Feedback model with SINR prediction

In LTE, channel feedback is based on SINR. One subframe contains multiple orthogonal frequency-division multiplexing (OFDM) symbols, arranged both in time and frequency domain [5]. OFDM symbols are transmitted with different channel states, which means specific SINR can be measured for each OFDM symbol.

The SINR from link quality measurement, expressed as γ, can be defined as:

$$\gamma = \frac{G_0 P_0}{\sum_{j=1}^{N} G_j P_j + \sigma_n^2}, \quad (1)$$

where G_0 is the channel gain for the desired signal with power P_0, G_j is the channel gain for the interfering signal with power P_j, σ_n^2 is the thermal noise power, and N is the number of interfering cells. Then, multiple SINRs within the subframe could be compressed into an effective SNR [6]. Several methods to achieve SINR compression exist, such as the Effective Exponential SNR Mapping (EESM) in [7]. The effective SNR is finally adopted as the metric, such that the suitable CQI is selected according to the SNR-CQI

This research was partly supported by the UMIC excellence cluster of RWTH Aachen Universty.

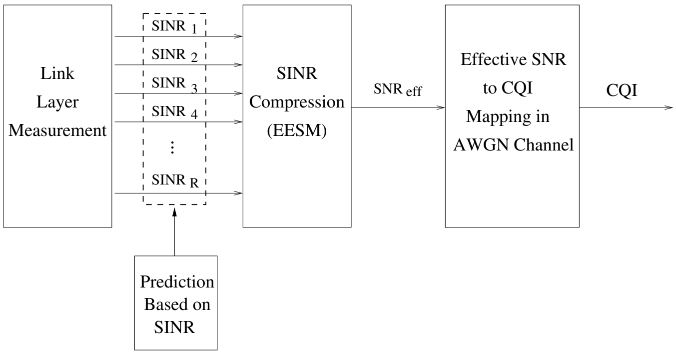

Fig. 1. CQI feedback model based on SINR prediction

mapping scheme over an equivalent additive white Gaussian noise (AWGN) channel [8]. The selected CQI is reported from UE to eNodeB after k subframes. The SNR-CQI mapping function can be obtained by intensive simulation.

In the proposed feedback model, the derived CQI is calculated according to the predicted SINRs in k ms, as shown in Figure 1. As a result, UE will report the CQI derived based on the predicted SINRs to eNodeB, instead of the CQI derived from current SINRs.

The temporal correlation of time-varying channel is commonly characterized by the Jakes' model. However, with the presence of many other factors, the second-order statistics of SINR have no closed form expression [9]. Therefore, the robust prediction using extrapolation is adopted. The predicted SINR for future time $t+k$, expressed as $\hat{\gamma}(t+k)$, is obtained as:

$$\hat{\gamma}(t+k) = L(\gamma(t), \gamma(t-1), ..., \gamma(t-p+1)), \qquad (2)$$

where t is the time for CQI feedback at UE side, L is the extrapolation function and p is the time window length that is equal to the number of previous SINRs used for prediction.

In order to improve the quality of extrapolation prediction, the range of SINR shall be considered. SINR varies within a limited range in a time period, and the range of SINR for one period could be obtained from previous SINRs in the time window. Thus, the predicted SINR $\hat{\gamma}(t+k)$ should fulfil the conditions as:

$$\hat{\gamma}(t+k) \leq \max(\gamma(t), \gamma(t-1), ..., \gamma(t-p+1)), \qquad (3)$$

$$\hat{\gamma}(t+k) \geq \min(\gamma(t), \gamma(t-1), ..., \gamma(t-p+1)), \qquad (4)$$

where $\max(\cdot)$ is the function to find the maximal value and $\min(\cdot)$ is the function to find the minimal value. If the predicted SINR is beyond the range, the prediction may lose its accuracy and shall be dropped.

To obtain the changing tendency of future SINRs and also save storage space, the time window length p shall be chosen appropriately. In fast varying channel, some previous subframes could be outdated and thus ineffective for prediction. And for a fading channel varying slowly, a large p could be beneficial for a precise SINR prediction.

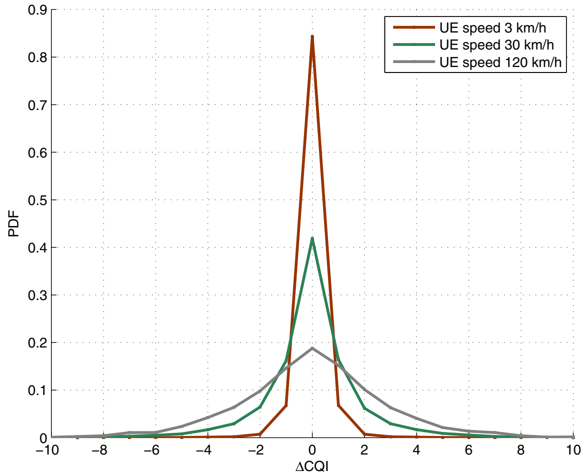

Fig. 2. PDF of CQI difference with 4 ms CQI feedback delay and 800 MHz carrier frequency at UE speed 3 km/h, 30 km/h and 120 km/h

TABLE I
THE MAXIMUM CQI DIFFERENCE FOR PREDICTION

UE speed [km/h]	ΔCQI_{speed}	$P(\mid A_p - A_c \mid > \Delta CQI_{speed})$
3	2	0.74%
30	6	1.00%
120	8	0.64%

III. CQI DIFFERENCE STATISTICS

When CQI is derived based on the predicted SINRs, the CQI difference statistics shall be taken into consideration. Usually, the difference between the CQI after a feedback delay and the current CQI is within a limited range. In Figure 2, the probability density function (PDF) of CQI difference with 4 ms CQI feedback delay is shown for UE speed 3 km/h, 30 km/h and 120 km/h respectively, assuming the carrier frequency is 800 MHz. In Figure 2, it is shown that when UE speed is 3 km/h, the probability of CQI difference larger than 2 is almost zero. As a result, in this case, it is not reliable if the CQI derived based on the predicted SINRs has a difference larger than 2 compared with the current CQI.

In Figure 2, it is also shown that when the UE speed is 30 km/h and 120 km/h , the probability of CQI difference larger than 6 and 8 is almost zero respectively.

Therefore, if the current CQI is expressed as A_c and the CQI derived based on the predicted SINRs is expressed as A_p, the predicted CQI shall fulfil the condition as:

$$\mid A_p - A_c \mid \leq \Delta CQI_{speed}, \qquad (5)$$

where ΔCQI_{speed} is the maximum difference according to the specified UE speed.

The maximum difference ΔCQI_{speed} is chosen, such that the probability of CQI difference larger than ΔCQI_{speed} is not higher than 1%. In Table I, the appropriate maximum difference ΔCQI_{speed} and the corresponding probability of CQI difference larger than ΔCQI_{speed} obtained from simulation are shown for different UE speeds.

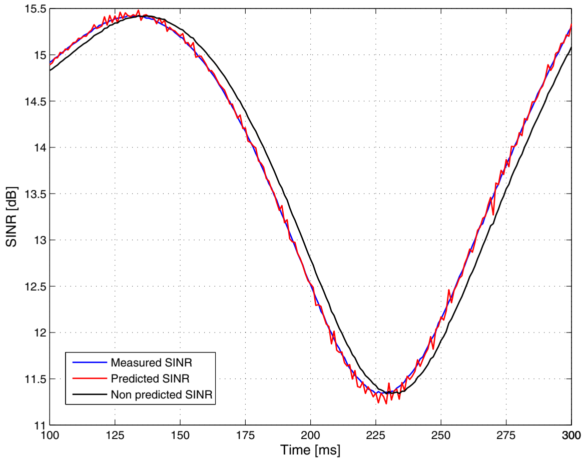

Fig. 3. Predicted SINR and non predicted SINR compared with measured SINR at UE speed of 3 km/h

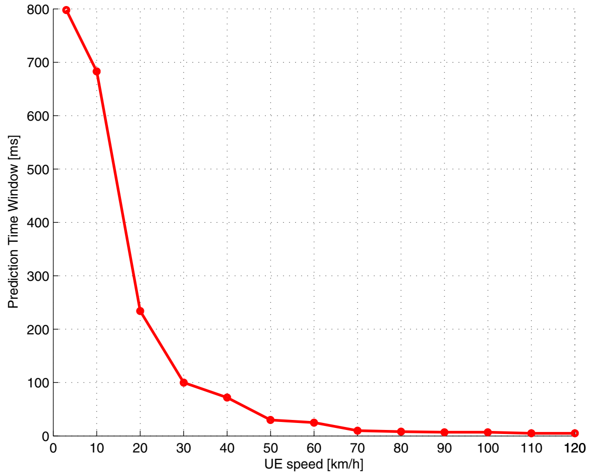

Fig. 4. Time window length for SINR prediction at different UE speeds

As a result, if the condition above can not be fulfilled, the CQI derived based on the predicted SINRs could be treated as unreliable CQI and shall be replaced by the unpredicted current CQI.

IV. Evaluation

The channel feedback model with SINR prediction has been validated through simulation. In the simulation, a single moving UE is placed in a cell with radius of 500 m. The cell is surrounded by 18 interfering cells. The transmission method is single-input and single-output (SISO). Rayleigh fading channel is used for modelling the transmission in urban environment. Linear extrapolation is used for SINR prediction. The simulation parameters are summarized in Table II.

TABLE II
Simulation parameters for SINR prediction

Bandwidth	1.4 MHz
Carrier frequency	800 MHz
Thermal noise density	-174 dBm/Hz
Total eNodeB transmit power	46 dBm
Pathloss model	COST 231 Walfish-Ikegami NLOS [10]
Shadow fading	absent
CQI feedback delay	4 ms
CQI report period	1 ms
Retransmission	HARQ
Channel knowledge	perfect

Figure 3 compares the predicted SINR and the non predicted SINR with the measured SINR, at UE speed of 3 km/h. It is shown that the non predicted SINR is always outdated, compared with the measured SINR. As long as the measured SINR changes smoothly, the predicted SINR could match the measured one perfectly.

In order to minimize the prediction error, the optimal time window length p is obtained through simulation in practical systems. The optimal time window length at different UE speeds is shown in Figure 4. It is shown that the time window

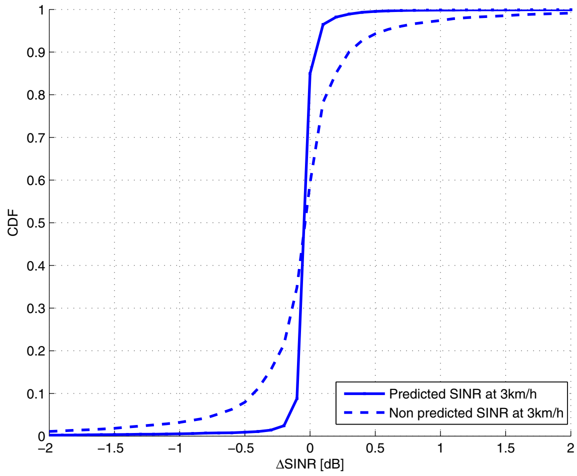

Fig. 5. CDF of SINR error both for predicted SINR and non predicted SINR at UE speed of 3 km/h

length decreases when the UE speed increases. That is because in fast fading channel, lots of previous subframes could be ineffective for prediction. For a fading channel varying slowly, a large window length p is necessary for precise SINR prediction.

To further evaluate the SINR prediction scheme, the cumulative distribution function (CDF) of SINR error $\Delta SINR$ is tested both for predicted SINR and non predicted SINR. $\Delta SINR$ is equal to the SINR currently used for deriving CQI minus the measured SINR after a CQI feedback delay. In Figure 5, the CDF of $\Delta SINR$ both for predicted SINR and non predicted SINR at UE speed of 3 km/h is depicted. It is shown that when the UE speed is 3 km/h, the non predicted SINR error is ranged from about -2 dB to 2 dB, while the predicted SINR error is ranged from about -0.5 dB to 0.5 dB. Moreover, the CDF curve of $\Delta SINR$ from predicted SINR

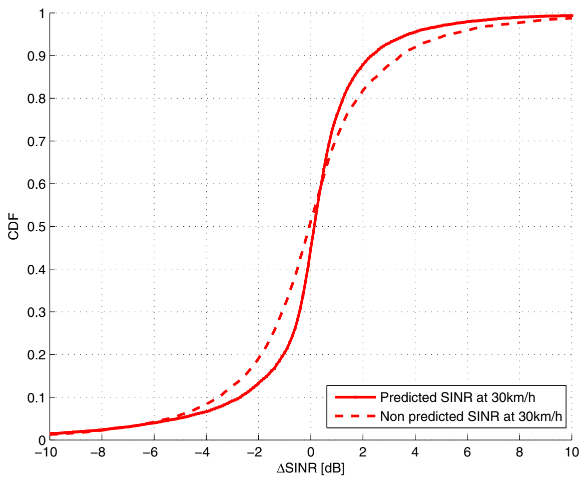

Fig. 6. CDF of SINR error both for predicted SINR and non predicted SINR at UE speed of 30 km/h

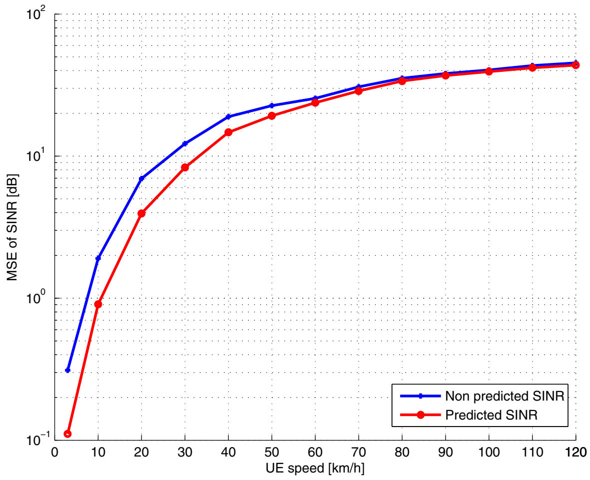

Fig. 7. MSE of both predicted SINR and non predicted SINR at different UE speeds

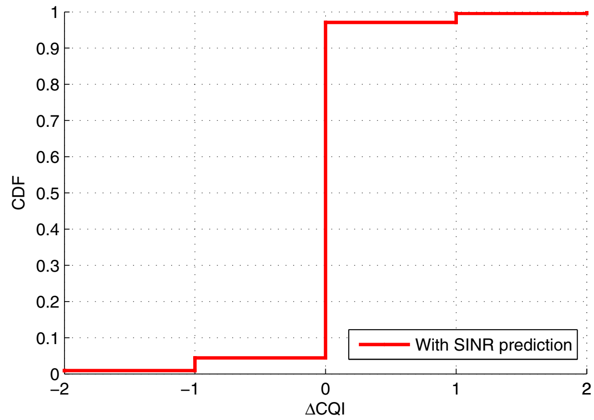

Fig. 8. CDF of ΔCQI for the feedback model with SINR prediction at UE speed 3 km/h

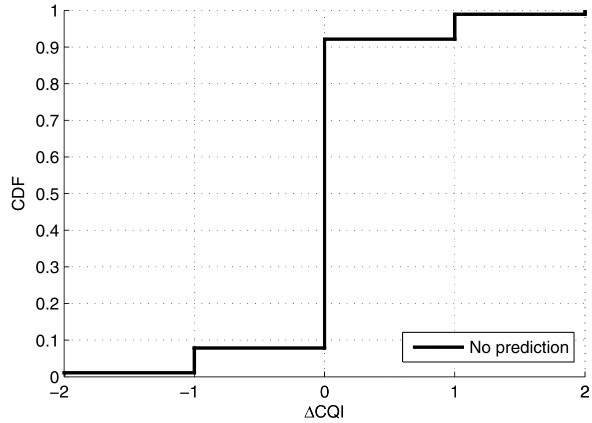

Fig. 9. CDF of ΔCQI for the feedback model without SINR prediction at UE speed 3 km/h

increases more sharply at about 0 dB. As a result, at UE speed of 3 km/h, the SINR prediction scheme could obtain SINR value closer to the SINR after a CQI feedback delay than the scheme without SINR prediction.

In Figure 6, the CDF of SINR error both for predicted SINR and non predicted SINR at UE speed of 30 km/h is depicted. It is shown that when the UE speed is 30 km/h, the non predicted $\Delta SINR$ and the predicted $\Delta SINR$ are both ranged from about -10 dB to 10 dB. However, the CDF curve of $\Delta SINR$ from predicted SINR increases more sharply at about 0 dB. As a result, at UE speed of 30 km/h, the SINR prediction scheme could also obtain SINR value closer to the SINR after a CQI feedback delay than the scheme without SINR prediction.

The mean squared errors (MSEs) of both the predicted SINR and non predicted SINR are compared at different UE speeds in Figure 7. The predicted SINR is better than the outdated SINR at the UE speed from 3 km/h to 60 km/h, because the MSE of predicted SINR is lower. The effect of SINR prediction is obvious when the UE is at a low speed. When the UE speed is higher than 60 km/h, the MSEs of predicted SINR and non predicted SINR are almost the same. However, in urban area, UE normally moves at a low speed. Thus, the feedback model with SINR prediction can provide good performance.

In Figure 8 and Figure 9, the CDFs of CQI error ΔCQI both for the feedback model with and without SINR prediction at UE speed 3 km/h are shown. It is shown that the CDF curve of ΔCQI for the feedback model with SINR prediction increases more sharply at the point of ΔCQI equal to 0. Thus, at UE speed 3 km/h, the feedback model with SINR prediction could report CQI that is closer to the most appropriate CQI after a CQI feedback delay of 4 ms, compared with the feedback model without SINR prediction.

The MSE of CQI both for the feedback model with and without SINR prediction at different UE speeds is also shown

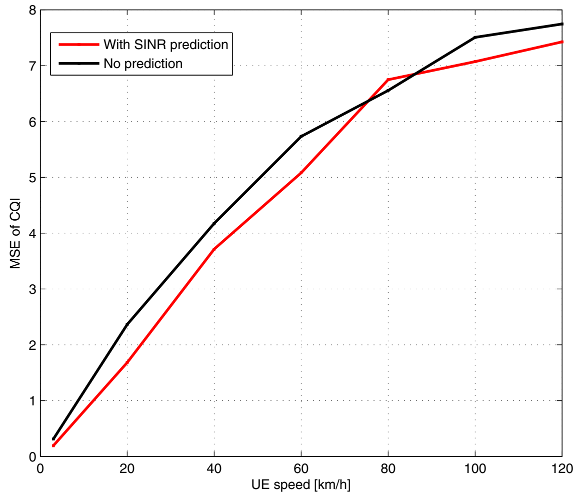

Fig. 10. MSE of CQI for the feedback model with and without SINR prediction at different UE speeds

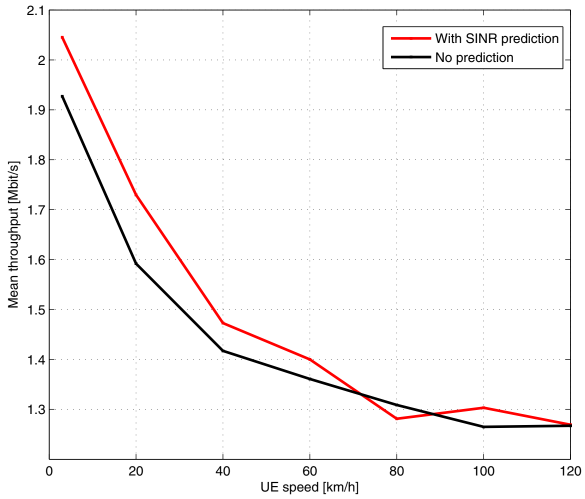

Fig. 11. Mean throughput of the feedback model with and without SINR prediction at different UE speeds

in Figure 10. It is shown that the feedback model with SINR prediction could achieve less CQI mean squared error when the UE speed is approximately from 3 km/h to 60 km/h. However, when UE speed is very high, the CQI MSE of SINR prediction model may be larger than that of no SINR prediction. That is because the SINR errors achieved by predicted SINR and non predicted SINR are almost the same at high UE speed.

In LTE systems, if the CQI used for transmission is higher than the most appropriate CQI for the current channel state, there is a high probability that the transmission is unsuccessful. Thus, the corresponding subframe can be regarded as erroneous and retransmission shall be performed. The retransmission can be performed at most 3 times for one erroneous subframe. The hybrid automatic repeat request (HARQ) model proposed in [11] is used to account for the effect of retransmission. If the used CQI is not higher than the most appropriate CQI, the transmitted subframe could be regarded as error free. Then, the throughput of each transmission can be calculated accordingly.

In Figure 11, the mean throughput achieved by the feedback model with and without SINR prediction at different UE speeds is shown. Although the performance of SINR prediction is degraded at high UE speed, the feedback model with SINR prediction could achieve larger mean throughput when the UE speed is approximately from 3 km/h to 60 km/h. Thus, when UE moves at low speed in urban area, the channel feedback model with SINR prediction is more efficient to improve transmission throughput than the feedback model without SINR prediction.

V. Conclusion

The channel feedback model with SINR prediction is capable of predicting the channel state when UE moves at low speed in urban area. The SINR prediction can provide more precise information than the outdated SINR for channel state feedback. The evaluation results prove that the SINR prediction using extrapolation is a robust approach at low UE speed. The channel feedback model with SINR prediction can improve the performance of LTE systems.

References

[1] 3GPP, "LTE; evolved universal terrestrial radio access (E-UTRA); multiplexing and channel coding," 3GPP TS 36.212 version 8.8.0 Release 8, January 2010.

[2] ——, "LTE; evolved universal terrestrial radio access (E-UTRA); physical channels and modulation," 3GPP TS 36.211 version 8.8.0 Release 8, October 2009.

[3] ——, "LTE; evolved universal terrestrial radio access (E-UTRA); physical layer procedures," 3GPP TS 36.213 version 8.8.0 Release 8, October 2009.

[4] H. Dai, Y. Wang, C. Shi, and W. Zhang, "The evaluation of CQI delay compensation schemes based on Jakes model and ITU scenarios," in *Vehicular Technology Conference (VTC Fall), 2012 IEEE*, September 2012.

[5] 3GPP, "LTE; evolved universal terrestrial radio access (E-UTRA); base station (BS) radio transmission and reception," 3GPP TS 36.104 version 8.12.0 Release 8, June 2011.

[6] J. Ikuno, S. Pendl, M. Simko, and M. Rupp, "Accurate SINR estimation model for system level simulation of LTE networks," in *2012 IEEE International Conference on Communications*, Ottawa, Canada, June 2012.

[7] S. Donthi and N. Mehta, "An accurate model for EESM and its application to analysis of CQI feedback schemes and scheduling in LTE," *Wireless Communications, IEEE Transactions on*, vol. 10, no. 10, pp. 3436–3448, October 2011.

[8] C. Mehlfuehrer, M. Wrulich, J. Ikuno, D. Bosanska, and M. Rupp, "Simulating the Long Term Evolution physical layer," in *Proc. of the 17th European Signal Processing Conference (EUSIPCO 2009)*, Glasgow, Scotland, August 2009.

[9] K. Hamdi, "On the statistics of Signal-to-Interference Plus Noise Ratio in wireless communications," *Communications, IEEE Transactions on*, vol. 57, no. 11, pp. 3199–3204, November 2009.

[10] 3GPP, "3rd generation partnership project; technical specification group radio access network; spatial channel model for multiple input multiple output (MIMO) simulations," 3GPP TR 25.996 version 10.0.0 Release 10, March 2011.

[11] J. Ikuno, M. Wrulich, and M. Rupp, "Performance and modeling of LTE H-ARQ," in *International ITG Workshop on Smart Antennas (WSA 2009)*, Berlin, Germany, February 2009.