The Evaluation of CQI Delay Compensation Schemes Based on Jakes' Model and ITU Scenarios

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***Abstract*—This paper addresses the evaluation of channel quality indicator (CQI) delay compensation schemes considering the impact of signaling interaction delay between evolved node B (eNodeB) and user equipments (UEs). The Jakes' model and International Telecommunication Union (ITU) channel models are introduced, which are the representatives of simple and complex simulation environments, respectively. The channel characteristics and the variation of CQIs of four typical scenarios are analyzed in detail. We then propose two types of CQI delay compensation schemes, namely weighted mean scheme (WMS) and prediction scheme based on normalized least mean square (NLMS-PS). Evaluation results show that both of these schemes do not work well on ITU channel models because system performance of complex simulation environment depends on not only the accuracy of CQI, but also the combined effects of the scheduling and other factors. However, these proposed schemes can boost the system performance effectively based on Jakes' model when the CQI delay is less than 5 ms.**

***Index Terms*—CQI delay compensation schemes, Jakes' model, ITU channel models**

I. Introduction

The Long Term Evolution (LTE) is one of the systems beyond the third generation (3G). It has the ability to provide up to 100 Mbps in the downlink and 50 Mbps in the uplink [1]. As one of the key link adaptive technologies, adaptive modulation and coding (AMC) technology can improve the system throughput by adjusting coding rate to fit the instantaneous channel state information. Channel quality indicator (CQI) is derived by user equipment (UE) based on an unrestricted observation interval in time and frequency. The CQI index is restricted between 0 to 15 and each of them indicates a combination of modulation and coding schemes [2]. The accuracy of CQI plays an important role on the effectiveness of AMC schemes. However, CQI is not always reliable due to channel estimation error, CQI quantization error and CQI feedback delay.

Particularly, there is a time delay between the subframe UE calculating CQI and the subframe evolved node B (eNodeB) using it. The CQI used in eNodeB is not equal to the CQI experienced as reception, resulting in a transport format not suitable for the channel conditions. Thus, the downlink system performance will be degraded. According to [3] and [4], the CQI delays consist of three parts: CQI measuring delay, CQI feedback delay and CQI processing delay, which are depicted in Fig. 1. CQI measuring delay and processing delay are far less than CQI feedback delay. Therefore, without loss of generality, three parts of CQI delays are unified as a whole named CQI feedback delay in the following paper.

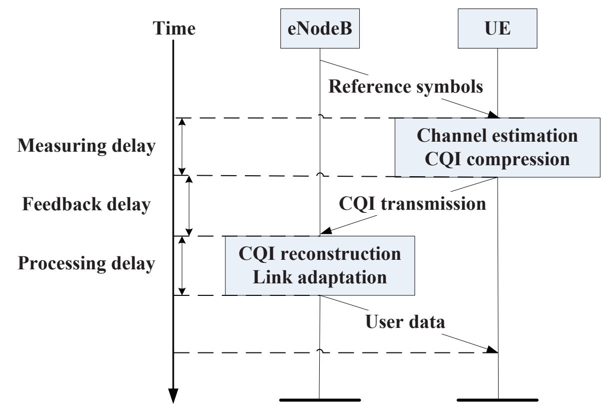

Fig. 1. Time delay of CQI feedback in LTE systems

Recently, there are some literatures concerning the design of link adaptive schemes to deal with the CQI delay issues. In [5], the authors analyzed the impact of channel estimation error and feedback delay on system performance. [6] concerned about how to define CQI feedback interval to reduce the effect of CQI feedback delay on system performance. An signal to interference rate (SIR) average algorithm was proposed to improve the performance of link adaptation in [7]. To reduce effect of time delay, [8] presented a CQI adjustment scheme used in High Speed Downlink Packet Access (HSDPA) system with the help of assistant information reported by UE. [9] improved the accuracy of CQI by predicting CQI on the basis of designing weight vector. Different from improving the accuracy of CQI in the literatures above, the throughput optimization algorithm named FLA in HSDPA was investigated in [10], whose idea is a long-term process on CQI to achieve the best block error ratio (BLER). Now it is widely used in LTE systems due to its excellent performance. We will introduce FLA in section V for analysis.

In this paper, we focus on the evaluation of CQI delay compensation schemes. Unlike most pervious works, we not only propose two CQI delay compensation schemes to deal with CQI delay, but also perform extensive simulation on the basis of Jakes' Model in [11] and LTE systems adopting International Telecommunication Union (ITU) channel scenarios

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detailed in [12]. Thus, evaluation results conducted in this paper is much more comprehensive and reliable. In addition, the variation of the ITU channels and CQIs without delay in LTE systems are analyzed, which are not considered in the approaches aforementioned.

The rest of this paper is organized as follows: Section II introduces the system models and channel characteristics. Section III formulates the problem and presents the variation of CQIs in LTE systems. In section IV, two types of CQI delay compensation schemes are proposed. The system-level simulation results are given in Section V and finally draw conclusion in Section VI.

II. System Model

In this section, we present two representative channel models in detail, namely Jakes' model and ITU channel models, which stand for simple simulation environment and complex simulation environment, respectively. Note that in complex simulation environment like LTE systems adopting ITU channel models, the scheduling, Hybrid Automatic Repeat Request (HARQ) and other factors are consistent with the baseline simulation assumptions specified in [13].

A. Jakes' Model

Jakes' model is first proposed in [11], for which the channel variation is time-related. Specifically, the channel model can be mathematically expressed as follows.

$$\mathbf{H}_t = \rho_d \mathbf{H}_{t-\tau} + \sqrt{(1-\rho_d^2)}\mathbf{E}, \tag{1}$$

where $\rho_d = \mathbf{J}_0(2\pi f_D \tau)$ stands for coefficient of time correlation and it obeys the distribution of the first class of zero-order Bessel function that $\mathbf{J}_0(z) = \sum_{k=0}^{\infty}(-1)^k \frac{z^{2k}}{2^{2k}(k!)^2}$, f_D means the maximum Doppler shift and τ denotes the CQI time delay. Besides that, $\mathbf{E}$ is a zero mean additive white Gaussian noise (AWGN) matrix whose covariance is the identity matrix. Note that $\mathbf{E}$ and $\mathbf{H}$ are independent.

B. ITU Channel Models

To compare with Jakes' model, we adopt four typical ITU channel scenarios: 1) Urban micro-cell scenario (UMi), 2) Urban macro-cell scenario (UMa), 3) Rural macro-cell scenario (RMa) and 4) Suburban macro-cell scenario (SMa).

According to the requirements of channel generation in [12] and the analysis of channel change in [14], we can get that Doppler shift $\upsilon_{n,m}$ leads to phase shift and plays a dominant role on the variation of channel. The bigger $\upsilon_{n,m}$ is, the faster channel changes. The Doppler shift $\upsilon_{n,m}$ is denoted as

$$\upsilon_{n,m} = \frac{\parallel v \parallel \cos(\varphi_{n,m} - \theta_v)}{\lambda_0}, \tag{2}$$

where v stands for the speed of UE and $\cos(\varphi_{n,m} - \theta_v)$ is in the range of $(-1, 1)$. Equation (2) can be simplified approximately as follows.

$$\upsilon_{n,m} \propto \frac{\parallel v \parallel}{\lambda_0} \propto \parallel v \parallel f_0, \tag{3}$$

where f_0 stands for carrier frequency.

According to equation (3), Table I can be obtained on the basis of parameters given in [12]. Obviously, channel can be sorted as SMa>RMa>UMa>UMi in accordance with the change order from fast to slow. To further validate the conclusion above, the system-level simulation is performed based on LTE release 8 specification. We assume 1200 ms of effective simulation step. Fig. 2 and Fig. 3 depict the real part and the imaginary part of channel response coefficient in four ITU channel scenarios, respectively. It is clear that UMi scenario owns the slowest channel change and the channel of SMa scenario change the fastest. The channels of four ITU

TABLE I
Doppler shift in typical ITU channel scenarios

Scenario	f_0 (GHz)	v (km/h)	$\upsilon_{n,m}$
UMi	2.5	3	7.5
UMa	2	30	60
RMa	0.8	120	96
SMa	2	90	180

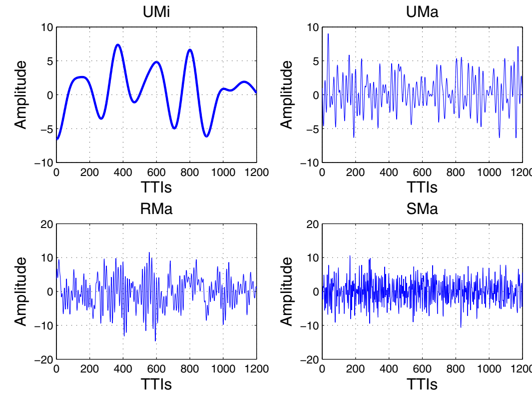

Fig. 2. Real part of channel response coefficient in four ITU channel scenarios

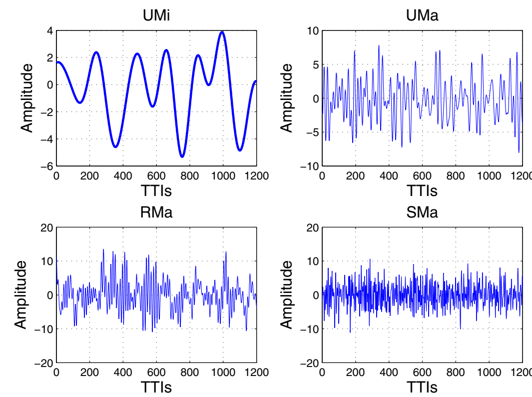

Fig. 3. Imaginary part of channel response coefficient in four ITU channel scenarios

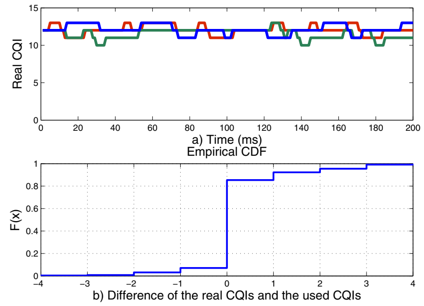

Fig. 4. Variation of CQIs in UMi scenario

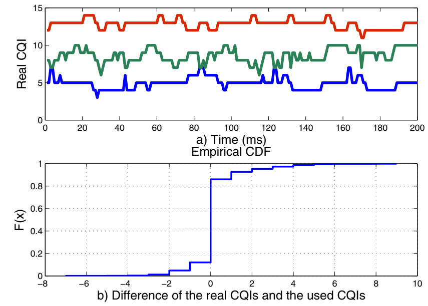

Fig. 6. Variation of CQIs in RMa scenario

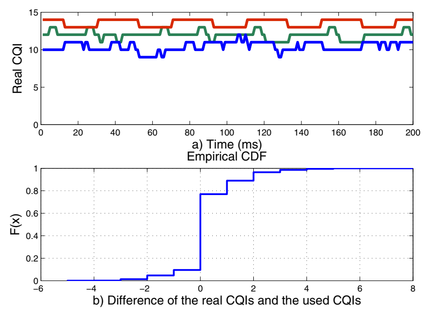

Fig. 5. Variation of CQIs in UMa scenario

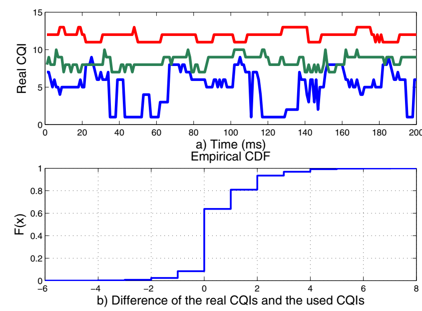

Fig. 7. Variation of CQIs in SMa scenario

scenarios can be ordered as SMa>RMa>UMa>UMi from fast to slow, which is in accordance with results in Table I.

III. Problem Formulation

In order to formulate the optimization problem, we first study the variation of CQIs in four ITU scenarios by the system-level simulation. Assume that at time t, the real CQIs without delay is denoted as A_t and the CQIs used by eNodeB is denoted as A_k. Without loss of generality, datas of three UEs are selected as the sampling unit. Simulation results are depicted in Fig. 4-7, which show a) the variation of the real CQIs A_t and b) the cumulative distribution function (CDF) curve of $A_t - A_k$.

From a) parts of Fig. 4-7, it is clear that the curves in UMi scenario is the smoothest, while SMa scenario has the most fluctuant curves. The curves of UMa and RMa scenarios are smoother than SMa, but more fluctuant than UMi. Meanwhile, A_t in UMi scenario get a higher value than those in other scenarios, relatively, since the channel condition of UMi scenario is better. It is concluded that in the view of both curves' smoothing degree and curves' value, UMi scenario is the best and UMi>UMa>RMa>SMa, which is consistent with the results in section II-B

The b) parts of Fig. 4-7 show that the real CQIs equal to the used CQIs ($A_t = A_k$) in UMi, UMa, RMa and SMa scenario accounts for almost 70%, 60%, 70% and 50%, respectively. In UMi scenario, $A_t - A_k \in [-4, 4]$, which is the smallest in all scenarios. RMa scenario suffers the biggest difference between A_t and A_k, since the difference is able to reach 10. For UMa

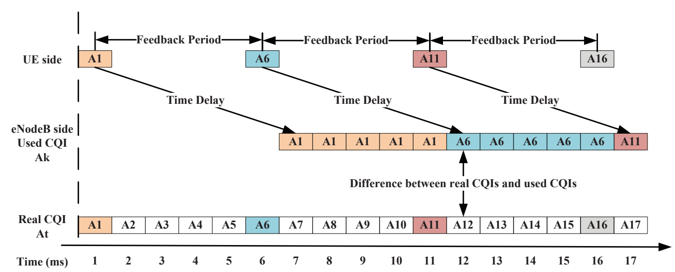

Fig. 8. Timing relationship of CQIs

and SMa scenarios, $A_t - A_k \in [-6, 8]$, but the probability of $A_t - A_k = x$, integer $x \in [-6, 8]$ is indeed different. Considering significant difference between A_t and A_k, SMa scenario is the worst in all scenarios.

Assume CQI feedback period is denoted as p and time delay is d. In general, $p = 5$ ms and $d = 6$ ms. Thus, we can get the timing relationship of CQIs in Fig. 8, which shows the performance loss occuring after 6 ms, when A_t is not equal to A_k. Through time relationship of CQIs, we can derive that $k = \lceil \frac{t-d}{p} \rceil$. Our problem can be formulated as designing $f(\cdot)$ function based on A_k to make $f(A_k)$ be closer to A_t. The problem is modeled as

$$\min_{f(\cdot)} |f(A_{\lceil \frac{t-d}{p} \rceil}) - A_t|. \tag{4}$$

IV. CQI Delay Compensation Schemes

In this section, we propose two CQI delay compensation schemes. The weighted mean scheme (WMS) is easier than the prediction scheme based on normalized least mean square (NLMS-PS) to adopt in system, whose idea is both designing the optimal weight to correct the used CQIs.

A. Weighted Mean Scheme

The WMS makes the weighted average of CQIs for a predefined time period. At time t, the unprocessed CQI is denoted as A_t. Denote by $A_t^{'}$ as the prediction CQI through WMS in eNodeB, then the $A_t^{'}$ can be expressed as

$$A_t^{'} = \sum_{i=1}^{T} w_i A_{t-i+1}, \tag{5}$$

where T denotes the time window for WMS. For simplicity, let $w_i = \frac{1}{T}$, $\forall i \in [1, T]$. Equation (5) is simplified as

$$A_t^{'} = \frac{1}{T} \sum_{i=1}^{T} A_{t-i+1}. \tag{6}$$

B. Prediction scheme based on NLMS

[15] proposed an one-step NLMS-PS, which has limitation because its scheme can predict CQI information of $d = 1$ ms delay, but is not suitable to apply in a practical system whose CQI has $d = 6$ ms delay. In this paper, we give out a d-step NLMS-PS, where d is a positive integer which can be any value. Note that one-step NLMS-PS is the special case of d-step NLMS-PS when $d = 1$.

1) Details of Scheme

Assume $\mathbf{w}(t)$ and $\mathbf{x}(t)$ represents filter tap weight vector and the filter input vector at time t, respectively.

$$\mathbf{w}(t) = [w_1(t), w_2(t), \cdots, w_M(t)], \tag{7}$$

$$\mathbf{x}(t) = [A_{t-1-d}, A_{t-2-d}, \cdots, A_{t-M-d}], \tag{8}$$

where M stands for the prediction filter length. The predicted CQI denoted as $y(t)$ is given as

$$y(t) = \mathbf{x}(t)\mathbf{w}(t)^T, \tag{9}$$

where $(\cdot)^T$ means transpose. The prediction error is given as

$$e(t) = A_t - y(t). \tag{10}$$

NLMS weight vector adaptation equation is modeled as

$$\mathbf{w}(t+1) = \mathbf{w}(t) + \upsilon \frac{\mathbf{x}(t)e(t)}{\mathbf{x}(t)\mathbf{x}^T(t)}, \tag{11}$$

where control parameter $\upsilon \in [0, 2]$.

Thus, the future CQI at time t can be denoted as

$$y^{'}(t) = \mathbf{x}(t+1)\mathbf{w}^T(t+1). \tag{12}$$

where $\mathbf{x}(t+1) = [A_{t-d}, A_{t-1-d}, \cdots, A_{t-M+1-d}]$. ENodeB should make scheduling and HARQ decisions on the basis of $y^{'}(t)$ at time t.

2) Parameters of Scheme

In this scheme, there are many factors affecting the performance of the scheme.

- **Stability of training sequence:** the more steady training sequence is, the better performance scheme has.
- **Step d:** step d should be small, relatively.
- **Length of filter M:** a suitable M is achieved by simulation on a practical system. When $d = 1$, $M = 5$ can satisfy performance requirement. When $d < 6$ and real CQIs are as training sequence, the best M for UMi, UMa, RMa and SMa scenarios is 28, 62, 32 and 92, respectively.
- **Control parameter υ:** usually assume $\upsilon = 1$.

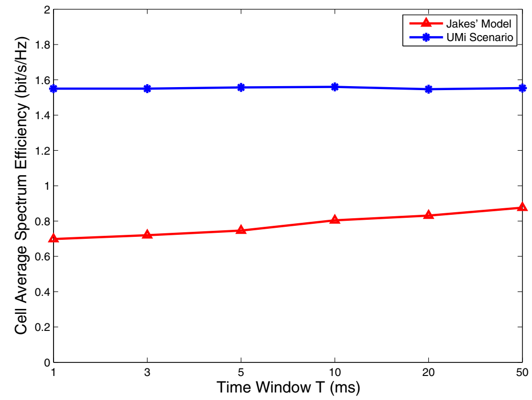

Fig. 9. Cell average spectrum efficiency versus time window T

V. Simulation Results

In this section, we give out simulation results on the basis of Jakes' model and ITU scenarios. Baseline represents basic configuration of LTE release 8, which will be used for performance comparison.

Without loss of generality, the performance of the WMS is only evaluated in Jakes' model and UMi scenario, which are depicted in Fig. 9. It is clear that WMS is of great help to boost cell average spectrum efficiency (CASE) of Jakes' Model, while does not work well on UMi scenario, effectively. For Jakes' model, WMS can achieve a significant performance gain. CASE increases with the increasing of time window T. When $T = 50$, the performance gain is 44% more than $d = 1$. This is because of the fact that WMS mitigates the impact of CQI delay and hence achieve a more reliable CQI. Thus, as a simple simulation environment without HARQ, scheduling and other factors, the accuracy of CQI plays a significant role on the system performance.

However, for UMi scenario containing scheduling, HARQ and other technologies, its CASE relatively maintains a stable value. Adopting WMS is able to improve the accuracy of each UE's CQI. But from the overall consideration, eNodeB will make scheduling and other decisions to maximize the throughput, which weakens the work of WMS. Thus, WMS is seen to be no effect on UMi scenario. Moreover, the channels of other ITU scenarios change faster than UMi as shown in Fig. 2 and Fig. 3. The performance of WMS will be the same poor as UMi scenario due to its fast varying channel losing the instantaneous CQI information. So the performance of complex simulation environment is the combined result of many factors, which not only depends on the accuracy of CQI.

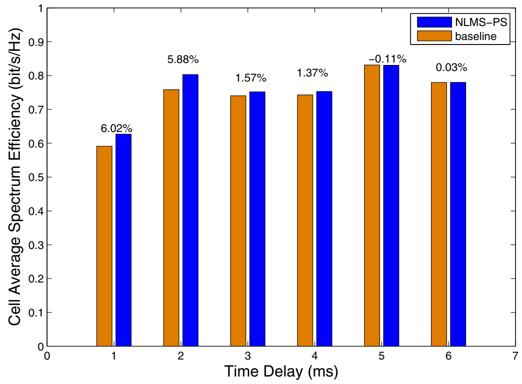

Fig. 10. Cell average spectrum efficiency versus time delay on Jakes' model

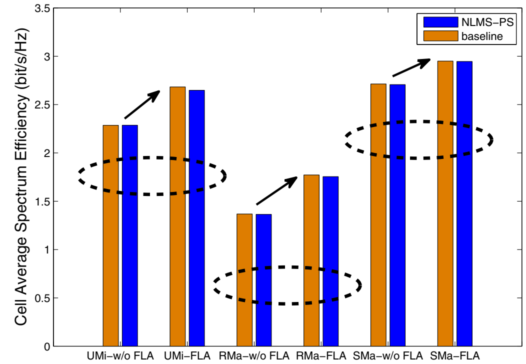

Fig. 11. Cell average spectrum efficiency of different ITU scenarios

As can be seen in Fig. 10, the NLMS-PS performs quite well on Jakes' model. The lowest CASE of baseline is achieved when $d = 1$, which is less than 0.6 bit/s/Hz. The reason is that fast varying channel of Jakes' model has a significant influence on the CQIs of each step (millisecond), while $d = 1$ makes the difference situation of two continuous CQIs in severity. Obviously, CASE of baseline is not dropping with the increase of d due to irregularity of channel changes. When d is set to be 1, 2, 3, 4, 5 and 6, CASEs improve 6.02%, 5.88%, 1.57%, 1.37%, -0.11% and 0.03% compared with baseline, respectively. However, when d increases, the benefit reduces, especially for $d = 5$ and 6. Considering the randomness of channel change, the NLMS-PS will degrade instantaneous channel information. Thus, the NLMS-PS has an ability to improve throughput for a simple simulation environment when time delay is smaller than 5 ms.

Looking at Fig. 11, one can note that there is almost no performance gains between baseline and NLMS-PS. This is expected, since the impact of the scheduling schemes and other factors occurs. One can also see that the system performance with FLA algorithm is significantly better than it without FLA, meaning that FLA is more effective than NLMS-PS when simulation environment is complex. The core of NLMS-PS is to improve the accuracy of CQI, while the idea of FLA is to achieve the best BLER by adjusting CQI in a long-term process. Since the complex simulation environment is a whole which should consider much more things, not only the accuracy of CQI, NLMS-PS is in vain to improve the system throughput. It is concluded that using NLMS-PS in a complex simulation environment clearly makes the performance not better even worse. However, using FLA is more reasonable.

VI. Conclusion

In this paper, we give out the evaluation of two CQI delay compensation schemes on the basis of both Jakes' model and ITU scenarios. These schemes fulfill the requirements to improve throughput of Jakes' Model, but cannot work well on ITU scenarios. For a complex system like ITU scenarios, its throughput is not decided by the accuracy of CQIs since multiple factors will weakens the effect of CQI. In addition, increasing the accuracy of CQIs is of great help to achieve a significant gain for a simple system like Jakes' model.

Acknowledgment

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References

[1] Y. Wang, T. Wang, L. Ling, and C. Shi, "On the evaluation of IMT-Advanced candidates: Methodologies, current work and way forward," in *Proc. IEEE WiCOM*, 2010, pp. 1 – 4.

[2] *Physical layer procedures*, 3GPP TS 36.213 V9.3.0 Std., 2010.

[3] Huawei., "System level evaluation of CQI compression schemes for E-UTRA," RAN1 meeting 48, St. Louis, USA, Tech. Rep. R1-071104, Feb. 2007.

[4] Panasonic., "Evaluation and error statistics for CQI reporting schemes," RAN1 meeting 46bis, Seoul, Korea, Tech. Rep. R1-062808, Oct. 2006.

[5] G. Oien, H. Holm, and K. Hole, "Impact of channel prediction on adaptive coded modulation performance in rayleigh fading," *IEEE Trans. Vehicular Technology*, vol. 53, no. 3, pp. 758 – 769, 2004.

[6] Huawei., "System level comparison of best-M and DCT-based CQI compression schemes," RAN1 meeting 47bis, Sorrento, Italy, Tech. Rep. R1-070368, Jan. 2007.

[7] H. Touheed, A. Quddus, and R. Tafazolli, "An improved link adaptation scheme for high speed downlink packet access," in *Proc. IEEE VTC*, May 2008, pp. 2051 – 2055.

[8] Z. Zhang, G. Tang, and D. Yang, "A CQI adjustment scheme for HSDPA system," in *Proc. IEEE VTC*, 2008, pp. 1433 – 1437.

[9] D. Martin-Sacristan, J. Monserrat, D. Calabuig, and N. Cardona, "HS-DPA link adaptation improvement based on Node-B CQI processing," in *Proc. IEEE ISWCS*, 2007, pp. 597 – 601.

[10] T. Cui, F. Lu, A. Goteti, V. Sethuraman, S. Rao, and P. Subrahmanya, "Throughput optimization in high speed downlink packet access (HS-DPA)," *IEEE Trans. Wireless Communications*, vol. 10, no. 2, pp. 474 – 483, 2011.

[11] W. Jakes, *Microwave mobile communications*. Wiley-IEEE Press; 2nd edition, 1994.

[12] *Guidelines for evaluation of radio interface technologies for IMT-Aadvanced*, ITU-R Report M.2135 Std.

[13] *Updated Calibration Information of Chinese Evaluation Group*, Chinese Evaluation Group Std. Std.

[14] D. GOKER, "robust link adaptation in HSPA evolved," M. Eng. thesis, Royal Institute of Technology (KTH), Stockholm, Sweden, Feb. 2009.

[15] H. Touheed, A. Quddus, and R. Tafazolli, "Predictive CQI reporting for HSDPA," in *Proc. IEEE International Symposium on PIMRC*, 2008, pp. 1 – 5.