CQI Reporting Imperfections and their Consequences in LTE Networks

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Abstract — **In modern wireless networks, the signal quality in wireless channel is estimated based on the channel quality measurements. The measurement results are used to select appropriate modulation and coding scheme for each transmission. The target of the link adaptation is to reach the desired block error rate operation point. Operation point and system performance could potentially be compromised by non-consistent / biased channel quality indicator reporting caused by, e.g., differently calibrated user equipments or hardware inaccuracies. This paper evaluates the extent of that phenomenon through different combinations of traffic types, bias settings and system loads by the means of fully dynamic system simulations. The in-depth results verified that on the system level the performance is not significantly impacted by reporting imperfections. Long term evolution is used as an example technology in this study, but the same concepts are applicable to other wireless technologies also.**

Keywords: Link adaptation, BLER target

I. INTRODUCTION

The tremendous success of wireless cellular *High Speed Packet Access (HSPA)* networks together with a "push" from competing technologies has fueled the development of cellular technologies even further. *Third Generation Partnership Project (3GPP)* has already completed first specification release of *Long Term Evolution (LTE)* [1] [2] which is considered to be the successor of HSPA.

LTE utilizes more simplified architecture and new radio access technologies, namely *Orthogonal Frequency Division Multiple Access (OFDMA)* in the downlink and *Single Carrier Frequency Multiple Access (SC-FDMA)* in the uplink. By introducing these changes among others the 3GPP has set a range of strict performance requirements for LTE [3]. For instance, LTE should achieve 2-4 times higher spectral efficiency than Release 6 HSPA is capable for.

When compared to the HSDPA, the adaptation to fast wireless channel variations LTE utilizes different techniques, since the transmission power is constant in the downlink. First of all, the *Modulation and Coding Scheme (MCS)* is adapted with frequent interval to the channel quality, based on the *User Equipment (UE)* feedbacks. Secondly, the *evolved NodeB (e-NodeB)* has capability to perform *Frequency Domain Packet Scheduling (FDPS)* to allocate the most suitable resources for the UEs. The purpose of the *Link Adaptation (LA)* is to handle the feedback information gotten from the UEs and then perform the selection of the appropriate MCS for the UE based also on the information about the allocation position in the frequency domain.

Channel Quality Indicator (CQI) plays a key role in the link adaptation process. It is a message sent by UE to e-NodeB describing the current downlink channel quality of the UE. It is measured from the reference symbols transmitted by e-NodeBs. The CQI measurement interval, measurement resolution in frequency domain, reporting mechanisms, etc. are all configurable parameters. These parameters have a tremendous impact on the system performance and their performance is studied e.g. in [4][5].

The *Inner Loop Link Adaptation (ILLA)* has the first hand responsibility on selecting the suitable MCS for the UE. The selection is done based on the mapping between the measured *Signal to Interference plus Noise Ratio (SINR)* of the reference symbols to the most appropriate MCS for an allocation. For various reasons the ILLA does not however always provide the perfect adaptation and therefore Outer Loop Link Adaptation (OLLA) function is also needed. The target of the OLLA is to adapt the MCS selection to provide certain *Block Error Rate (BLER)*. The target BLER (s.c. Operation Point) is usually set to provide optimal performance depending on whether retransmission mechanisms like *Automatic Retransmission reQuest (ARQ)* and/or *Hybrid ARQ (HARQ)* are utilized.

II. RESEARCH PROBLEM AND MOTIVATION

LTE UE radio transmission and reception requirements are specified in [6]. One of these requirements is related to how tightly the BLER operation point should be set. Operation point and system performance could potentially be affected by non-consistent CQI reporting by the UE. In other words non-consistent CQI reporting could lead to having suboptimal BLER operation point. Non-consistent CQI reporting by the UE can be caused by e.g. hardware inaccuracy, misconfiguration or calibration.

The purpose of this study is to evaluate how system level performance is affected if UEs report biased (more aggressive and/or non-aggressive) CQI values instead of the ones that they actually should in their current radio channel conditions. Thus,

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bias is directly related to the initial offset value of *Outer Loop Link Adaptation (OLLA)* which is then being corrected. In this study bias is referred also as initial LA/OLLA offset.

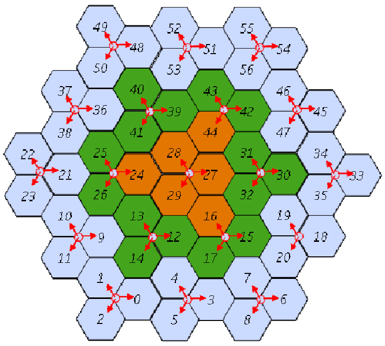

Figure 1. Simulation scenario

III. SIMULATION METHODOLOGY AND ASSUMPTIONS

This study has been performed using a fully dynamic time driven system simulator which supports both uplink and downlink directions with a symbol resolution. In this study only downlink direction is simulated in detail and uplink traffic is considered as ideal to keep the scope of this study within reasonable limits.

We have used periodically reported full CQI information (separately from each *Physical Resource Block (PRB)*)) in these studies to show the impact of bias in worst-case scenario as very accurate CQI information would be available without the bias. The actual bias is studied with two different alternatives: fixed and random bias. Fixed bias means a situation where all terminals have (the same) fixed bias in the beginning of the call whereas with random bias the terminals have bias set according to uniform distribution. Both in the random and fixed bias cases, the bias is constant during the whole call for each UE.

As implied earlier, in this study we assume both an inner loop and an outer loop LA unit. The OLLA algorithm imposes an offset margin that is subtracted from the SINR measurements in the CQI manager before being used by the inner loop LA to estimate the supported data rate, and modulation and coding scheme. The OLLA algorithm aims to control the experienced average BLER for the first transmissions, and it follows the same principle as the traditional outer loop power control algorithm for dedicated channels in IS-95 and WCDMA and for HSDPA. Hence, if an *Acknowledgement (Ack)* is received for a first transmission, the offset factor, A, is increased by A_{up} decibels (defined with a parameter), while it is decreased by A_{down} decibels if a *Negative Acknowledgement (Nack)* is received. Offset factor has limit for maximum and minimum to prevent situations where channel conditions change significantly and OLLA would take very long time to shift the offset back to the other way. The ratio between the step up and down determines the average BLER that the OLLA converges to, i.e.

$$\text{BLER} = 1 / (1 + A_{up} / A_{down}). \qquad (1)$$

Simulations have been conducted with *Constant Bit Rate (CBR)* type of service which has certain amount of source data and thus certain amount of packets (varied throughout the simulations). See more detailed parameters from TABLE III. Different file sizes do not model any specific applications but are rather just selected to see at which size the CQI bias does have an impact. The smallest sizes like 10kB and 50kB are, however, very small when considering the traffic volume of the modern network applications.

These studies have been conducted in a macro cellular scenario presented in Figure 1. The scenario consists of 19 base stations where two inner tiers (i.e. the orange and green areas) are the one were mobiles are allowed to move. Statistics are collected from the innermost tier (orange cells). Third tier (i.e. cells indicated with light blue colour) are normal active BSs which have background load adapting to statistic BS load. In addition to the adaptive load of the third tier, in this study also the two innermost tiers are adjusted to have minimum level of cell load (0-100 %) which is reached generating artificial (background) load if UEs (avg. 10 per cell) themselves do not reach the target.

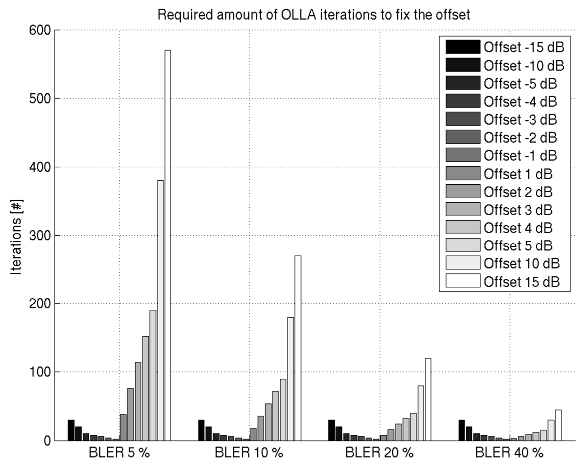

Figure 2. Example of required OLLA iterations to meet the BLER target

IV. PREANALYSIS

As described above, the biased CQI reporting impacts to the performance of OLLA as it needs to fix also the bias in addition to its normal operation. The purpose of this section is to briefly analyze the background of OLLA operation and how the performance would change due to the bias.

TABLE I. EXAMPLE OLLA PARAMETERS

BLER	A_{up}	A_{down}
5%	0.5	~ 0.026
10%	0.5	~ 0.056
20%	0.5	0.125
40%	0.5	~ 0.333

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Normally, when the UE sends its CQI reports to the e-NodeB the scheduler will do the scheduling assignments according to the received and processed information. The purpose of the e-NodeB link adaptation units is to modify the received CQI information and thus allocated MCS so that certain BLER target is met. This means in practice that UE will experience delay before the certain level of BLER is converged. The delay depends on how high difference there is between OLLA starting point and the actual channel situation. Figure 2. illustrates an example of how many OLLA iterations it takes to fix the offset between the starting point of OLLA and the actual channel situation of the UE. The numbers of iterations are calculated for different BLER levels according to the Equation (1) with A_{up} being 0.5 dB. The resulting Adown values for each of the used BLER percentages can be found in TABLE I. As the figure shows, positive offsets, i.e., situations where the OLLA starts with more conservative MCSs are changed with relatively low pace when compared to the negative offsets where MCSs would be more aggressive. The reasoning behind this is simple, too aggressive MCSs can cause BLER levels to rise rapidly and thus affect to quality of service that users experience whereas more moderate MCSs are likely only to drop the BLER levels. The downside of more moderate MCSs is, however, the drop in user throughput levels, presuming that packets would go through with more aggressive MCSs.

When considering that the bias could further increase the offsets it is possible that system level performance would be affected. However, when considering that the range of actual bias values that would present in the network should remain on quite low level (+-1 dB) the impact should be able to be mitigated quite well by the OLLA unit.

TABLE II. MAIN SIMULATION ASSUMPTIONS

Feature/Parameter	Value / Description
Operational Bandwidth	10 MHz
Duplexing	FDD
Number of sub-carriers	600
Network synchronicity	Asynchroneous
Sub-frame length	1 ms
Cell layout	57 hexagonal macro cells
NodeB Inter site distance (ISD)	500 m
Multipath channel	Typical Urban
UE velocity	3 kmph
UE receiver	2 Rx MRC
Outerloop link adaptation	BLER target 0.2 A_{up} 0.5 dB A_{down} 0.125 dB Max offset 15 dB Min offset -15 dB
Channel quality indicator	Measument period 5 ms PRBs per CQI 6 Reporting delay 2ms SINR error variance 1 dB Bias +-[0, 1, 2, 4]

TABLE III. CBR TRAFFIC ASSUMPTIONS

Feature/Parameter	Value / Description
File size	[10, 50, 100, 200, 1000, 5000] kbytes
Packet size	1500 bytes
Packet inter-arrival time	1 step

V. SIMULATION RESULTS

The system level performance is evaluated in this study mainly through normalized *Spectral Efficiency (SE)*, user throughput, first transmission BLER per call and distribution of OLLA offset collected at the end of the call. SEs and user throughputs are normalized so that bias 0 dB, i.e., no bias case is the reference point. User throughputs are presented as percentile bars and e.g. 10 percentile bar height means that 10 percent of the calls experience throughput of that or less.

A. Performance with fixed bias

Spectral efficiency of CBR type of service with different source data amounts is illustrated in Figure 3. As that figure shows the impact of fixed bias is moderately sensitive to the amount of data that is transmitted during the call. If the calls are very short (deductable from the user throughputs and the amount of source data, illustrated in Figure 4. and Figure 5.) the performance can be impacted in terms of SE, depending on the magnitude of the bias. The impact is higher if more aggressive bias (negative values) i.e. higher MCS is selected than the actual CQI would imply. However, if the call length is more realistic, i.e. there is more data and the packets during the call; the performance starts to become more balanced.

User throughputs for 10 and 90 percentiles illustrated in Figure 4. and Figure 5. show that the trend is similar to SE figures above, i.e., the impact of bias starts to diminish once there is reasonable amount packets/data during the call. Moreover, small and moderate positive bias (non-aggressive) can even improve the performance in terms of 90 % user throughput where the MCSs are generally quite high. On another hand more aggressive bias results in 10-15% loss for UEs in similar situation.

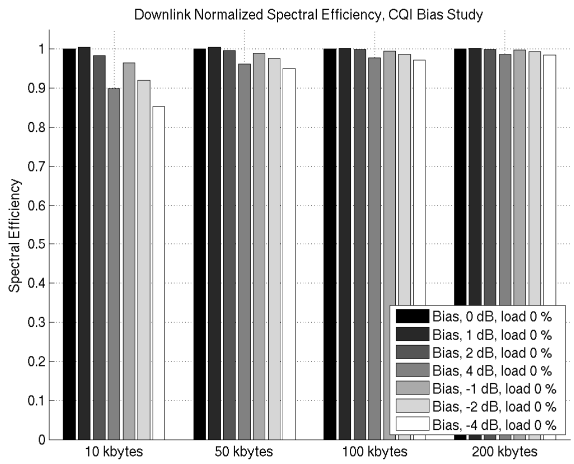

Figure 3. Normalized Spectral Efficiency, Fixed Bias

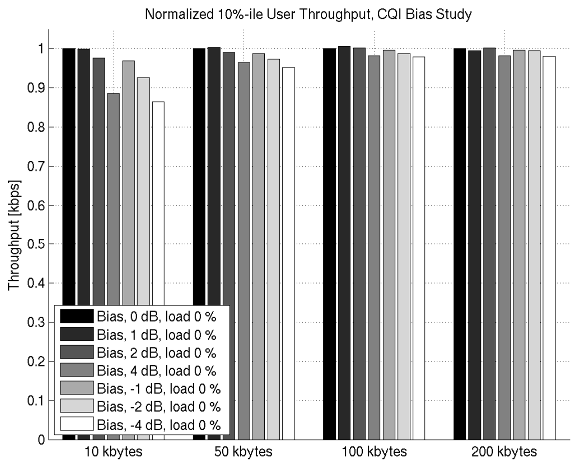

Figure 4. User Throughput, 10 Percentile, Fixed Bias

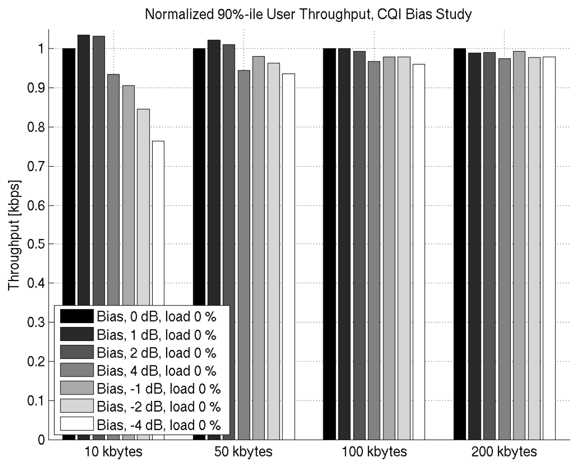

Figure 5. User Throughput, 90 Percentile, Fixed Bias

The reason why call length and amount packets affects to the fact that bias becomes more insignificant is that with longer calls OLLA has enough time to correct it. Thus, the impact of bias is directly proportional to the amount of OLLA iterations available during the call. With large file sizes the bias is corrected already when only e.g. 10% of file has been sent and then the rest of the file can be sent without the impact of bias. This naturally decreases the effect of the bias when e.g. throughput of the whole call is evaluated. This, behavior is confirmed by Figure 6. and Figure 7. which illustrate how well OLLA is able to converge the offset (CQI bias) when the call length is longer. Moreover, it should be also noted that even with ideal offset and low amount packets OLLA will not have time to converge in general as confirmed by distribution with higher amounts of source data. The relatively big amount of very low OLLA offsets in the end of the calls are results of UEs being in very good position where even the most aggressive MCSs are not enough aggressive.

B. *Performance with random bias*

The spectral efficiency with more realistic bias, which models the penetration levels of, e.g., different manufacturers' or differently configured terminals, is shown in Figure 8. In simulation environment realistic bias means bias which is randomized separately to each UE. As the figure shows, with random bias the performance is, expectedly, much more robust against the bias even with high range of bias values and low amount of data. Similarly to fixed bias study, with reasonable amount of source data the OLLA has enough samples and has time to fix the bias and thus it is not visible in SE. Moreover, it can be seen that the system load 0-100 % does not have noticeable impact to how bias impacts the performance.

Finally, first transmissions BLERs are illustrated in Figure 9. and Figure 10. As those figures show, if there is adequate amount of data the BLER operation point, which was assumed to be 20 %, in these simulations is maintained quite well, regardless of the bias. With lower amount of source data the OLLA operation point remains on higher level than the desired 20% target even without bias.

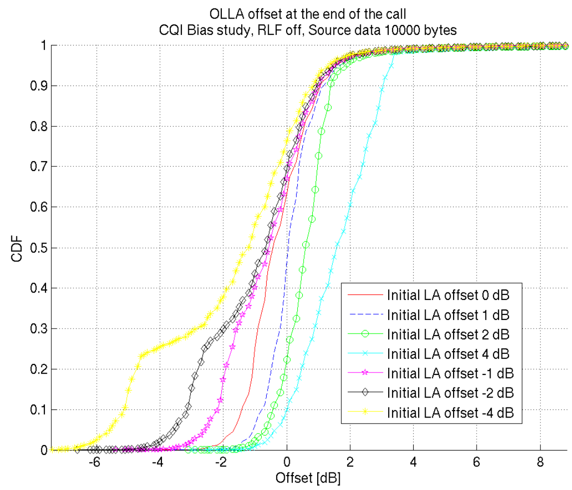

Figure 6. OLLA offset distribution, fixed bias, 10 kbytes source data

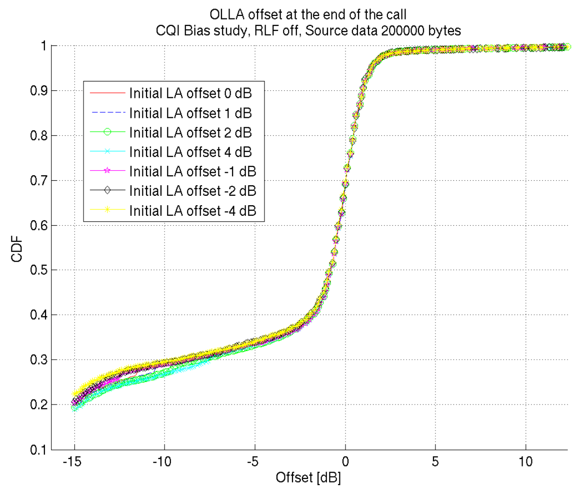

Figure 7. OLLA offset distribution, fixed bias, 200 kbytes source data

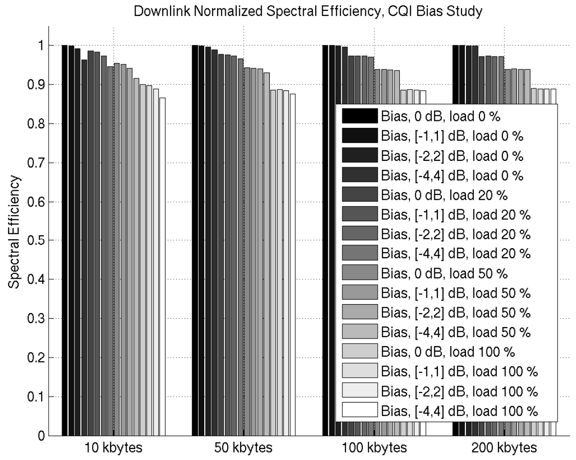

Figure 8. Normalized Spectral Efficiency, Random Bias

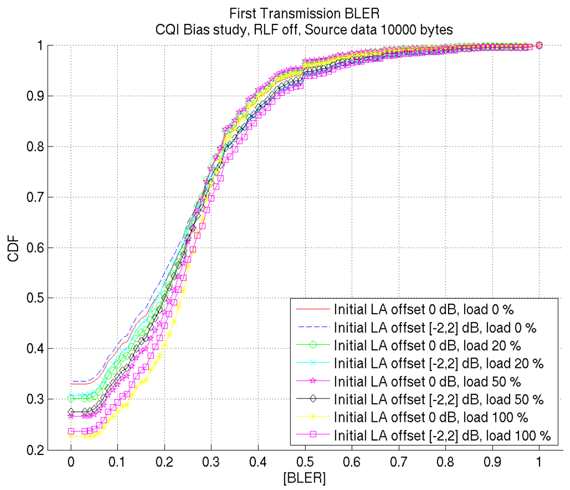

Figure 9. First transmission BLER per call, 10 kbytes data, Random Bias [-2,2] dB

VI. CONCLUSION

In this study we have shown with fully dynamic simulations how non-consistent CQI reporting by the UE impacts to the system level performance. Performance was evaluated with different combinations of traffic types, bias settings and bias values.

The results show that the system level performance can be affected by biased CQI values only when there is very low amount of data / packets and the bias is relatively high. In practice it is not, however, very likely that all of the users would have such a small amount of data and large bias. It is shown that OLLA is able to correct +-2 dB (random) bias range without affecting the spectral efficiency or user throughput but even higher bias values can be compensated with reasonable amount of data i.e. with high enough number of OLLA iterations.

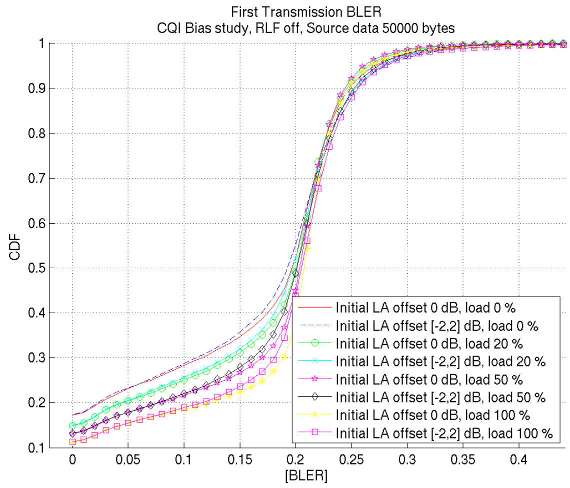

Figure 10. First transmission BLER per call, 50 kbytes data, Random Bias [-2,2] dB

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