Self-Optimization Algorithm for Outer Loop Link Adaptation in LTE

A. Durán, M. Toril, F. Ruiz, and A. Mendo

Abstract—In this letter, a novel algorithm for improving outer loop link adaptation (OLLA) convergence speed in the downlink of Long Term Evolution (LTE) is presented. The proposed heuristic algorithm adjusts the OLLA initial offset parameter based on OLLA adjustment histograms of large activity connections. The algorithm is validated with a connection-level simulator, fed with real connection traces collected from a live LTE network. Results show that average network block error rate, user throughput and spectral efficiency can be improved by properly adjusting the initial OLLA offset parameter.

Index Terms—Mobile network, long term evolution (LTE), outer loop link adaptation (OLLA), self-optimization.

I. INTRODUCTION

LINK adaptation is a key process in mobile communications systems. The aim of link adaptation is to cope with changes in radio link conditions by dynamically selecting the optimum modulation and coding scheme (MCS) for each connection. Achievable user throughput largely depends on proper MCS selection. If MCS is too conservative, instantaneous channel capacity is not fully exploited. In contrast, if MCS is too aggressive, block error rate (BLER) increases and radio link efficiency is impaired.

Most existing link adaptation schemes consist of an inner loop link adaptation (ILLA) selector and an outer loop link adaptation (OLLA) corrector. The aim of ILLA is to select the most suitable MCS based on link quality measurements. In its simplest form, it assigns an MCS to each reported channel quality indicator (CQI). On the other hand, the aim of OLLA is to correct reporting inaccuracies and delays. A common approach is to correct the reported CQI based on hybrid automatic repeat request (HARQ) positive and negative acknowledgments sent by the user equipment (UE) [1].

In the literature, most efforts have been focused on the design of robust link adaptation schemes to deal with CQI reporting inaccuracies. In [2], a scheme that takes CQI age into account is proposed for High Speed Downlink Packet Access (HSDPA). In [3], several CQI processing strategies are proposed in HSDPA. In [4], an OLLA scheme that adapts signal quality thresholds based on medium access control (MAC) acknowledgments in IS-856 is proposed. A similar scheme is proposed in [1], which adds an adaptive offset to signal quality measurements to deal with handset measurement and CQI errors, uplink reporting delays and detection errors in LTE. However, few studies have evaluated the problem of OLLA convergence and its impact on the performance of short connections. The analyses presented in [5] and [6] show that link adaptation schemes based on adaptive thresholds may suffer from slow convergence with strongly biased CQI reporting. In [7], it is shown that such a slow convergence is a major issue in current LTE networks due to the prevalence of short connections.

In this letter, a novel self-optimization algorithm for adjusting the initial offset parameter in a classical OLLA scheme 55 for LTE downlink is presented. The proposed algorithm sets the initial offset parameter of all connections to the value obtained at the end of large activity connections, where OLLA has reached steady state and has adapted to the actual channel conditions. As a result, average radio link efficiency and user throughput increase and overall BLER decreases. The proposed algorithm is validated with a connection-level simulator fed with statistics from real connection traces. During the experiments, the proposed algorithm is compared with the case where OLLA parameters are set to the default values suggested by vendors. This letter is organized as follows. Section II presents a theoretical analysis of OLLA imperfections to justify the need for optimizing OLLA parameters. Section III describes the proposed self-optimization algorithm for OLLA. Section IV presents the performance analysis and Section V summarizes the conclusions.

II. PROBLEM FORMULATION

Fig. 1 shows the structure of the classical link adaptation scheme for the downlink [1]. In this scheme, the UE measures downlink signal-to-interference-plus-noise ratio (SINR), $\gamma_m$, and sends CQI reports to the base station (eNB) on a per-transmission time interval (TTI) basis. The reported CQI values are processed at the eNB to build an estimate of the measured downlink SINR, $\hat{\gamma}_m$. The SINR measured by the UE differs from the

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from the real SINR by a systematic (i.e., bias) error term due to imperfections in the SINR measurement unit of the UE, and a random error term due to imperfections in channel estimation [8]. Such a difference can be expressed in logarithmic units as:

\[
\gamma_m(k, n) = \gamma(k, n) + e_s^\uparrow(k) + e_s^\downarrow(k, n),
\]

where \(\gamma_m(k, n)\) and \(\gamma(k, n)\) are the measured and real SINR of user (i.e., connection) \(k\) in TTI \(n\), and \(e_s^\uparrow(k)\) and \(e_s^\downarrow(k, n)\) are, respectively, the systematic and random errors introduced by the terminal of user \(k\) in TTI \(n\). In (2), dependence on indices \(k\) and \(n\) shows that the systematic error is constant during a connection, whereas the random error varies with each TTI [9].

At the eNB, the SINR derived from the received CQI is an estimate of the measured SINR used by the UE to compute the CQI value. Estimated and measured SINR differ by a systematic error term, due to differences in the mapping curves used by eNB and UE to derive SINR thresholds for each CQI, and a random error term, due to errors in the CQI feedback channel, the delay in the reporting process and deviations from the assumed channel conditions (e.g., multipath environment, user speed, . . . ) [8]. Thus,

\[
\hat{\gamma}_m(k, n) = \gamma_m(k, n) + e_s^\uparrow(k) + e_s^\downarrow(k, n)
\]

\[
= \gamma(k, n) + e_s^\uparrow(k) + e_s^\downarrow(k, n) + e_b^\uparrow(k) + e_b^\downarrow(k, n)
\]

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= \gamma(k, n) + e_s^\uparrow(k) + e_b^\downarrow(k, n),
\]

where \(\hat{\gamma}_m(k, n)\) is the estimate of \(\gamma_m(k, n)\) at the eNB, \(e_b^\uparrow(k)\) and \(e_b^\downarrow(k, n)\) are, respectively, the systematic and random errors introduced by the eNB for user \(k\) in TTI \(n\), and \(e_s^\uparrow(k)\) and \(e_s^\downarrow(k, n)\) are the total systematic and random errors for user \(k\) in TTI \(n\). Again, the systematic error introduced by the eNB is fixed, whereas the random error introduced by the eNB varies with each TTI.

The aim of OLLA is to compensate for systematic errors by applying an offset, \(\Delta_{\text{OLLA}}\), to the estimated SINR to compute an effective (i.e., corrected) SINR as:

\[
\gamma_{\text{eff}}(k, n) = \hat{\gamma}_m(k, n) - \Delta_{\text{OLLA}}(k, n).
\]

If \(\Delta_{\text{OLLA}}(k, n) = e_s(k)\), then \(\gamma_{\text{eff}}(k, n)\) is an unbiased estimator of the real downlink SINR experienced by the UE, which can be used by ILLA to select the proper MCS.

From (3), it is deduced that a positive value of \(\Delta_{\text{OLLA}}\) leads to a lower value of \(\gamma_{\text{eff}}\), which translates into a pessimistic interpretation of the reported channel conditions and the selection of a robust MCS. Conversely, a negative value of \(\Delta_{\text{OLLA}}\) leads to a higher \(\gamma_{\text{eff}}\), translating into an optimistic interpretation of the channel conditions and the selection of an aggressive MCS.

When \(\gamma_{\text{eff}}\) is calculated correctly, \(\gamma_{\text{eff}}\) matches the actual channel conditions, systematic errors are compensated and the best MCS is selected.

At the beginning of each radio resource control (RRC) connection, \(\Delta_{\text{OLLA}}\) is initialized to a fixed value, \(\Delta_{\text{ini}}\), defined on a cell basis. As the connection progresses, \(\Delta_{\text{OLLA}}\) is progressively modified by OLLA based on HARQ feedback. When a positive acknowledgment (ACK) is received, \(\Delta_{\text{OLLA}}\) is decreased by \(\Delta_{\text{down}}\); and when a negative acknowledgment (NACK) is received, \(\Delta_{\text{OLLA}}\) is increased by \(\Delta_{\text{up}}\). The ratio \(\frac{\Delta_{\text{down}}}{\Delta_{\text{up}}}\) controls the target BLER that OLLA converges to, given by

\[
\text{BLER}_{\text{T}} = \frac{1}{1 + \frac{\Delta_{\text{down}}}{\Delta_{\text{up}}}} \approx \frac{\Delta_{\text{down}}}{\Delta_{\text{up}}}, \quad \text{if } \Delta_{\text{up}} \gg \Delta_{\text{down}}.
\]

Typical values for \(\Delta_{\text{up}}\) and \(\Delta_{\text{down}}\) are 1 dB and 0.1 dB, respectively, to ensure quick recovery from high BLER situations and smooth convergence to equilibrium. These values yield a target 131 BLER of 0.1 (10%).

Note that the target BLER is only reached at the end of large activity connections, for which a large number of ACKs and NACKs are received by the eNB. For these connections, OLLA reaches steady state and \(\Delta_{\text{OLLA}}\) fluctuates around the proper value due to random system errors. In contrast, for small activity connections, convergence is not guaranteed, unless \(\Delta_{\text{OLLA}}\) is properly initialized. When \(\Delta_{\text{ini}}\) is too large, \(\gamma_{\text{eff}}\) is far above the actual channel conditions. This leads to an excessively conservative selection of the initial MCS and, therefore, user throughput is below the maximum achievable value. Considering a typical value of \(\Delta_{\text{down}} = 0.1\) dB, OLLA needs at least 10 consecutive successful transmissions (i.e., 10 ms) to compensate for a 1 dB bias in SINR reporting. This is 145 comparable to the average RRC connection activity in current LTE networks [7] and might prevent OLLA from reaching the optimum MCS before the connection is released. On the other hand, when \(\Delta_{\text{ini}}\) is too small, \(\gamma_{\text{eff}}\) is far above the actual 149 channel conditions and a too aggressive MCS is initially 150 selected. This causes high BLER figures and unnecessary 151 retransmissions, thus lowering the net user data flow. In both 152 cases, user throughput is negatively affected.

Other link adaptation schemes proposed in the literature [154] improve OLLA convergence speed, but they require changing 155 existing equipment and are thus not directly compatible with 156 currently deployed systems. In the absence of these schemes, a 157 cost-effective solution for legacy networks is to adjust the value 158 of \(\Delta_{\text{ini}}\) properly, as described next.

III. SELF-OPTIMIZATION ALGORITHM

In this section, an automatic algorithm for optimizing the initial OLLA offset parameter in LTE downlink is described. The motivation of the algorithm is first given and the details are presented later.

A. Motivation of the Algorithm

Fig. 2 represents three different realizations of the OLLA process for a sample connection, obtained with a statistical connection-level simulator. The figure shows the evolution of the OLLA offset with three different settings for the initial 169 offset parameter (i.e., \(\Delta_{\text{ini}} = -10, 10\) and 3 dB). It is observed that, for all settings, the offset converges to the same value 171 (i.e., 3 dB). This was expected since, in the steady state, the 172 offset fluctuates around a fixed value, representing the sum of 173 the bias terms for that specific connection (i.e., \(e_s^\uparrow(k) + e_s^\downarrow(k)\)). However, when \(\Delta_{\text{OLLA}}\) is initialized to an excessively large 175 value (10 dB), the connection takes longer to reach the steady 176 state, and conservative MCSs are used during the first TTIs of 177
The algorithm consists of three stages: filtering, aggregation and statistical computation. In the filtering stage, large activity connections are identified. To isolate large activity connections, an internal threshold parameter, $\Delta_{ini}$, is defined as the minimum number of HARQ positive and negative acknowledgment messages (i.e., ACKs + NACKs) to consider a connection as a large activity one. Only histograms for large activity connections are processed in subsequent stages. In the aggregation stage, histograms of large activity connections are aggregated into a single histogram as:

$$H^i_{\text{OLLAT}}[i] = \sum_{k=1}^{N_c} H^i_{\text{OLLAT}}(k)[i], \quad i = 1, \ldots, N, \quad (5)$$

where $i$ is the histogram bin index, $H^i_{\text{OLLAT}}$ are the $\Delta_{OLLAT}$ histograms of large activity connections, $k$ is the connection index, and $N_c$ is the number of large activity connections.

Finally, in the statistical computation stage, the optimized value of the initial offset parameter, $\Delta'_{ini}$, is computed as the median value of $H^i_{\text{OLLAT}}$, denoted by $\Delta'_{\text{OLLAT}}$.

The above-described optimization process can be executed periodically to adapt to changing network conditions. Likewise, the algorithm can consider the network as a whole, leading to a single global optimized value, or can be executed on a cell-by-cell basis, providing the best value for each cell.

### IV. PERFORMANCE ANALYSIS

A comparison of the network performance obtained with the default OLLA parameter settings against that obtained with the proposed self-optimizing algorithm is done. The analysis is carried out with a statistical connection-level simulator fed with real connection traces collected from a live LTE network. The aim of the analysis is to show that: a) OLLA convergence is an issue in current LTE networks, and b) tuning $\Delta_{ini}$ with the proposed algorithm can improve network performance significantly in a real scenario.

#### A. Simulation Setup

The analyzed trace dataset consists of 1744890 connections collected during 24 hours in 24 LTE cells in 4 sites selected at random. Cells are distributed in 2 carriers at 734 MHz and 2.132 GHz with 10 MHz and 5 MHz system bandwidth, respectively.

For each connection, trace data includes radio resource control (RRC) connection duration, average user packet data convergence protocol (PDCP) and radio throughput, total occurring time, HARQ activity (i.e., amount of ACKs + NACKs), and CQI and OLLA offset histograms. OLLA histograms contain 8 bins, whose limits are $[-\infty, -10, -7, -3, -1, 1, 3, 7, +\infty]$ dB, while CQI histograms contain 16 bins, ranging from CQI 0 to CQI 15.

A statistical connection-level simulator has been developed to analyze the time domain behavior of $\Delta_{OLLAT}$ and other relevant performance indicators of the connections. The inputs to the simulator are CQI and $\Delta_{OLLAT}$ cumulative distribution functions, built from traces on a per-connection basis. For each 252 connection, a random CQI is generated on a TTI basis from 253
The real CQI distribution. Then, the measured SINR is derived from the CQI value by using link-level mapping curves [10]. The real SINR is computed by adding bias and random error terms, as in (2). For large activity connections (i.e., activity ≥ $\Delta_{ini}$), the bias term is obtained from the median value $\Delta_{ini}$ of the OLLA offset histogram of that connection. For small activity connections, the bias term is obtained similarly from a histogram randomly selected from large activity connections.

Random errors introduced by the terminal and the eNB are modeled as Gaussian random variables with standard deviation $\sigma_f = 1$ dB [9] and $\sigma_b = 0.3$ dB [11]. The effective SINR at the eNB is obtained with (3), and MCS is selected based on SINR thresholds for a BLER of 10% derived from link-level simulations [10]. The actual BLER is estimated from the real SINR and the mapping curve corresponding to the selected MCS. Such a BLER value is used to randomly generate ACK or NACK messages, which are then used by OLLA to update the OLLA offset.

Three different OLLA parameter configuration approaches are compared. The first one is the current approach followed by the operator, where $\Delta_{ini}$ in downlink is set to 0 dB in all 275 cells of the network. This solution is used for benchmarking purposes. In a second approach, referred to as network-level optimization, the optimized value of $\Delta_{ini}$ is computed by applying the proposed algorithm to a dataset built by aggregating $\Delta_{ini}$ statistics in the 24 cells and 24 hours. In a third approach, referred to as carrier-level optimization, two values of $\Delta_{ini}$ are obtained by applying the proposed algorithm separately to the 282 cells of each carrier.

Method assessment is based on: a) the average spectral efficiency, estimated from the selected MCS and BLER probability [12], b) the average maximum user throughput, computed by multiplying the average spectral efficiency by the system bandwidth of the carrier frequency (5 or 10 MHz), and c) the average connection BLER, computed by mapping the real SINR measurements with link-level simulator curves [10].

### Table I

<table>
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<th>Optimization level</th>
<th>Default</th>
<th>Network</th>
<th>Carrier</th>
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<tbody>
<tr>
<td>$\Delta_{ini}$ [dB]</td>
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In this letter, a novel OLLA self-optimization algorithm has been proposed for LTE downlink. By processing connection 316 traces, the algorithm adapts the initial OLLA offset value to the median value observed in large activity connections, where 319 steady state is reached. With the optimized settings, OLLA converges faster, leading to increased user throughput and reduced retransmission rates. Such performance benefits are obtained without modifying existing network equipment. The 322 analysis of real connection traces has shown that the optimum 323 value of the initial offset parameter differs significantly from the 324 value that currently configured by operators. Future work aims at 325 evaluating the benefit of adjusting the initial offset parameter on a daily-, hourly- or a cell-by-cell basis.

### References


[11] M. Ni, X. Xu, and R. Mathar, “A channel feedback model with 3 dB [11]. The effective SINR at the eNB is obtained with (3), and MCS is selected based on SINR thresholds for a BLER of 10% derived from link-level simulations [10]. The actual BLER is estimated from the real SINR and the mapping curve corresponding to the selected MCS. Such a BLER value is used to randomly generate ACK or NACK messages, which are then used by OLLA to update the OLLA offset.

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