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An Energy-Efficient MIMO-Based 4G LTE-A Adaptive Modulation and Coding Scheme for High Mobility Scenarios

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Abstract: The paper investigates the effects of Users Equipment (UEs) mobility on the performance of 4G LTE-A under high data rate services. One of the key techniques supporting LTE services is Adaptive Modulation and Coding (AMC) in which the modulation scheme and the coding rate are adaptively changed to match the current channel conditions as reported by UEs. The mapping between Channel Quality Indicator (CQI) and Signal-to-Interference-plus-Noise Ratio (SINR) has a significant impact on the throughput of the cell, sector and hence the UEs. This paper proposes a new SINR to CQI mapping scheme that satisfies the current trends towards green environment with the prospects of reducing the power transmitted from the evolved Node Base station (eNodeB, or eNB) while still satisfying the Quality of Service (QoS) demanded by the UEs. We demonstrate that the proposed mapping method allow the UEs to report the minimum CQI to satisfy the desired QoS.

Keywords: LTE-A, Uplink, AMC, CQI, Mobility, System - Level Simulation, Spatial Multiplexing.

1. INTRODUCTION

In LTE-A, the quality of the received signal depends on macroscopic path loss, shadowing, multipath fading, interfering signals, and sensitivity of the receiver [1]. Link adaptation is used to alleviate the negative impacts of such variations, guarantying the QoS of UEs, and maximizing the system throughput.

There are three modulation orders supported in LTE-A, namely QPSK, 16 QAM and 64 QAM [1]. LTE-A systems apply AMC to maximize the throughput to cope with varying channel environments [2]. The modulation order and coding rate are determined based on the feedback Channel State Indicator (CSI), which is specified in terms of a 4-bit CQI [3]. The CQI index represents an indication of the data rate which can be supported by the channel taking into account the SINR and the characteristics of UE. This CQI is simply fed back by the UE to the eNB and is used as an input for the selection of modulation and coding schemes (MCS).

In the uplink, each UE reports an appropriate CQI to the eNB. AMC works as follows: based on the received SINR, a MCS is chosen in such a way that the data rate demanded by the UE is satisfied with a Block Error Rate (BLER) less than 10% (tunable) in the downlink transmission. The selection of MCS is accomplished on a single Transmission Time Interval (TTI) basis. Thus, every 1 ms the MCS might be adjusted [3]. As a result, CQI plays a key role in LTE-A systems. It should be noted that there exists two issues in regard to UEs with high mobility. First, channel fluctuation is fast. Second, transition from the serving cell to adjacent cells becomes very frequent for small sized cells, resulting in more handoffs.

As far as system-level simulations of LTE-A is concerned, many link-to-system mapping schemes have been recently proposed for MIMO-based LTE-A. In [2], SNR-CQI mapping is calculated before measuring the effective values. UEs estimate the CSI, then SNR is extracted and SNR-CQI mapping scheme is established. In [4], a novel SNR-CQI mapping scheme is proposed. The CQI calculation is improved by considering the impact of multipath delay spread using BLER to enhance the convergence of their proposed algorithm in Multi User (MU) MIMO systems.

In [5], a leakage-based precoding algorithm is proposed to determine more reliable CQI and to diminish user interference. A solution based on SNR

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conversion is proposed in [6]. In [7], the authors provided three factors that cause CQI errors. Among them, mobility of UEs is the most serious one. The effect of mobility on channel quality reflects on the size of multipath delay spread [8]. As the spread is increased, the transmission delay is increased too, and the channel quality becomes worse [9]. In [10] improved versions of Exponential Effective SINR Metric (EESM) and Mutual Information Effective SINR Metric (MIESM) algorithms are proposed. The CQI values are fed back by all UEs to inform eNB on the link quality of each UE. The CQI value is calculated based on a linear function to assist eNB in the process of allocating resources to all UEs. The sequence of mapping SINR into CQI in the physical layer model consists of three major steps as depicted in Figure 1.

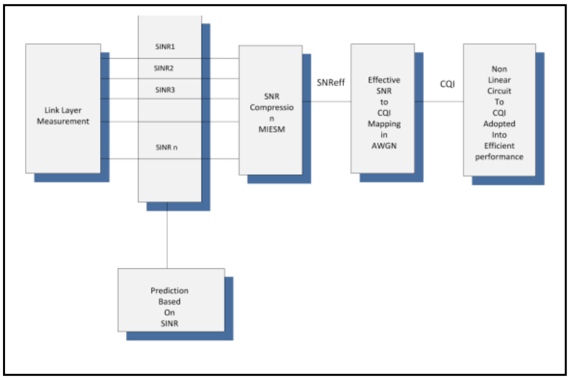

Figure1. CQI feedback model based on SINR prediction with nonlinear mapping

In the first step, the SINR is computed for all the allocated Resource Blocks (RBs) using the parameters of eNB. In the second step, (EESM/MIESM) effective SINR mapping transform these SINR into an equivalent SNR assuming an AWGN channel. Finally, the SINR values are converted into CQI according to a linear mapping function, which is reported to the serving eNB.

In this paper, we propose a new nonlinear function to quantize CQI values based on the UE's speed (or equivalently, Doppler frequency spread) such that the required QoS is achieved with minimal power to be transmitted from the eNB.

The rest of the paper is organized as follows. Section 2 provides a brief discussion on existing traditional SINR-CQI mapping techniques. The SINR and CQI mapping proposed in this paper are discussed in Section 3. System model and configurations are introduced in Section 4. Simulations results and Assessments are provided in Section 5. Finally, section 6 concludes the paper.

2. TRADITIONAL SNR-CQI MAPPING

In LTE system, each user selects the CQI based on channel estimation. Each UE seeks an optimal pair of modulation order and coding rate that provides the largest throughput when the BLER is less than 10% [1]. This approach, however, consumes significant computational resources from the battery-limited UEs. Hence, attempts to simplify the computational process and/or decrease the power consumed are highly desired. Simulations are needed to determine the optimal CQIs under different CSI conditions.

In this sense, UEs can obtain sensible CQIs, as long as the channel estimations are sufficiently accurate. In [10] the SNR-CQI mappings are obtained in various classical channel models based on practical measurements scenarios by 3GPP [3]. It is clear that one SNR value may correspond to different CQIs in different channel models. Such a difference is brought by a channel quality variation, which may due to variations of channel parameters other than SNR.

When a bandwidth of 20 MHz is used, this bandwidth is corresponding to 100 PRB. The received signal power of each PRB may be different due to frequency selective fading yielding 100 different instantaneous SINRs over all PRBs. There should be a mechanism to bring these SINRs into one effective SINR value which is then used to determine the MCS of the code-word. In this study, we used the EESM (Exponential Effective SINR Mapping), which is indeed a compression function for translating instantaneous channel state SINRs into an effective SINR. The effective SINR is then used to determine the MCS and estimate the BLER according to a separate simulation using a link-level performance in AWGN channel.

If each user reports the full CQI for both single- and multi-user modes, a huge amount of feedback is required while other CQIs remain unused for downlink transmission. Hence, we quantize the CQI for each Doppler shift using 2 bits while selecting the minimum CQI feedback with sufficient SINR. The method used to select the CQI values is based on the fact that the SNR of the transport block size (TBS) in AWGN channel for a BLER of 10% is increased in a step of 1 dB.

It is desired that the transmitter sends as many symbols as possible within the 10% BLER criterion. A high CQI value requires high SNR, i.e., a good channel condition, and the higher CQI value a UE reports; a larger transport block is transmitted. On the eNB side, a significant constraint in LTE MIMO downlink scheduling is that all RBs allocated to a given user in any given scheduling period have to use the same MCS. Once the eNB allocates the RBs to different UEs, the EESM is utilized to choose the MCS for the UEs as well. When the multiuser scheduler allocates several groups of RBs to one UE, with the corresponding CQI values fed back by this UE, the eNB can choose the proper MCS in the downlink transmission for the UE.

First of all, the eNB utilizes the corresponding CQI values of the allocated groups of RBs to get the SNR values with Table I [11]. Then, these SNR values are used to find the effective SINRs that are calculated by the UE in the previous sub-frame. Next, the UE determines the SNR values which are less than the effective SINR. Finally, the UE sends back these SNRs and their corresponding indices to represent the CQI value of the group of RBs.

TABLE I. MCS VERSUS SINR

Modulation	level	coding	Minimum receiver SNR(dB)	Bits
BPSK	1	1/2	3.0	1
QPSK	2	1/2	6.0	2
QPSK	3	3/4	8.5	2
16QAM	4	1/2	11.5	4
16QAM	5	3/4	15.0	4
64QAM	6	2/3	19.0	6
64QAM	7	3/4	21.0	6

3. THE PROPOSED SNR - CQI MAPPING

The proposed scheme is inspired by the desire to adapt the minimum CQI level for each UE in order to reduce the power transmitted by the eNB without sacrificing the QoS. This is demonstrated by comparing the actual CQI of UEs with three different speeds corresponding to f_d = 100, 300, and 400 Hz, where f_d is the Doppler frequency shift to that of a stationary user, f_d = 0 Hz. Next, the MCSs for UEs with velocities correspond to f_d ranging from between 100 Hz to 400 Hz i.e. (15-60) m/s are provided with the same CQI value since they possess almost equal SINR.

Given that there are too many factors involved in determining the system BLER, the SINR-CQI mapping is obtained by simulations. In our wok, we employ the system-level simulation developed by the research group at Vienna University [14] to obtain the CQI mapping in scenarios that mimic users with high mobility. The procedure starts by setting the channel conditions, such as pedB and vehA which also reveal the Doppler frequencies induced in relation to the velocity of the user involved.

Although there might be many ways to measure the wireless channel conditions, we believe that SINR is the best measure to quantify the quality of the channel. We consider a downlink OLSM MIMO implementation with two antennas at both the eNB and UE. The 'Best CQI' scheduler has been implemented for different users' speeds. It should be emphasized that there is only a few studies that focused on the effects of users' speeds [12], [13]; however, none to the best of the authors' knowledge have considered the effects of different user speeds and number of users on LTE system performance in the context of MIMO implementation.

4. SYSTEM MODEL AND CONFIGURATION

To evaluate the effects of the mobility of UEs, system-level simulations are performed. The important parameter settings are listed in Table II. A macro cell scenario was considered, consisting of a hexagonal grid comprising seven cells, each covered by three-sectors with a site-to-site distance of 500m in rural and suburban environments. We consider the ITU pedestrian B (pedB) and Vehicular-A (vehA) to account for scenarios involving users with wide range of mobility ranging from pedestrian to vehicles moving at high speeds.

TABLE II. BASIC SYSTEM LEVEL PARAMETERS USED IN THE SIMULATION

parameters	settings
Carrier frequency	2GHz
Bandwidth	20MHz
Tx and Rx mode	OLSM 2×2 MIMO
Number of users/cell	2 UEs per cell
User speed m/s.	0 — 60
Channel model types	pedB and vehA
Scheduler type	'best CQI' [8]
Feedback channel delay	3 TTI
Time of simulation	1000 TTI

Many packet scheduling algorithms have been considered such as Round Robin (RR), Proportional Fair (PF) and Best CQI. In [8] it is shown that the first strategy allows the users take turns in sharing resources, without taking the instantaneous channel conditions into consideration. In this case more radio resources must be given to communication links with bad channel conditions. Furthermore, as RR algorithm assigns resources to the users regardless of the channel information, this leads to lower overall system performance [8]. For those reasons above we choose best CQI as scheduling type in our simulation.

5. SIMULATION RESULTS AND ASSESSMENTS

We focus our simulations on macro cell scenarios in rural and suburban environment. The simulations have been considered for two UEs according to the setting displayed in Table II. The simulation has been carried out for 1000 TTI and evaluated BLERs of the target systems which are below 10%. The user speed was chosen as the main parameter to evaluate the effects of mobility on CQI values in each run. The CQI values versus user speed calibrated in terms of Doppler frequency shift is shown in Figure 2 from which it is clear that for lower speed, the UE encounters higher CQI.

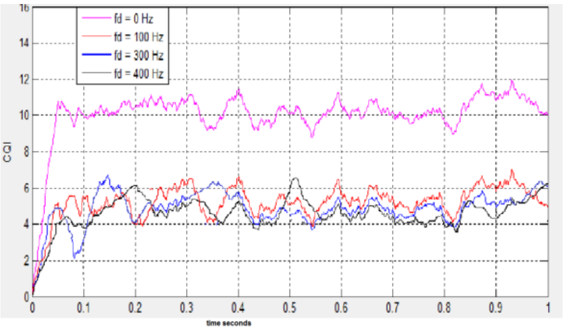

Figure 2.CQI with time for Doppler frequency = 0, 100, 300 and 400 Hz.

Next, the range of values of CQI, denoted by ΔCQI over which the CQI is bounded is extracted versus speed and tabulated as shown in Table III. The impact of CQI on the SINR have also been measured for different channels conditions (AWGN and different Doppler frequencies channels) and plotted as shown in Figure 3. The average throughput for a single user and a sector, have been investigated together with BLER as shown in Figures 4 and 5, respectively. Finally the throughputs for different user Doppler frequency (0, 100, 300, and 400) were shown in Figure 6.

TABLE III. THE CQI DIFFERENCE FOR PREDICTION

User speed m/s	User speed Km/hr	Doppler frequency	ΔCQI	SNR(dB)
0	0	0	9-12	22
15	54	100	4-7	18
45	162	300	4-7	18
60	216	400	3-6	15

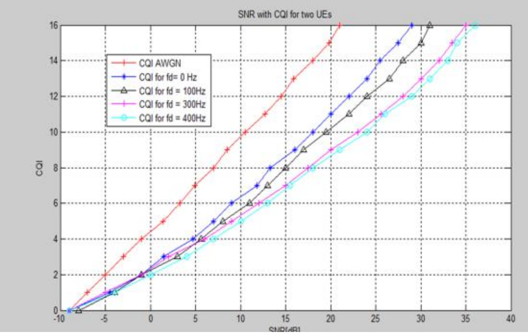

Figure 3.CQI versus SINR for Doppler frequency shifts of 0, 100, 300 and 400 Hz.

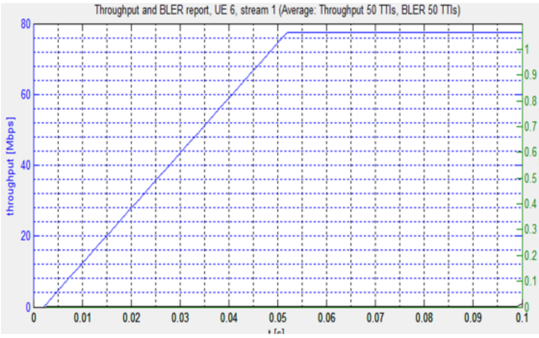

Figure 4. Average throughput for a stationary UE

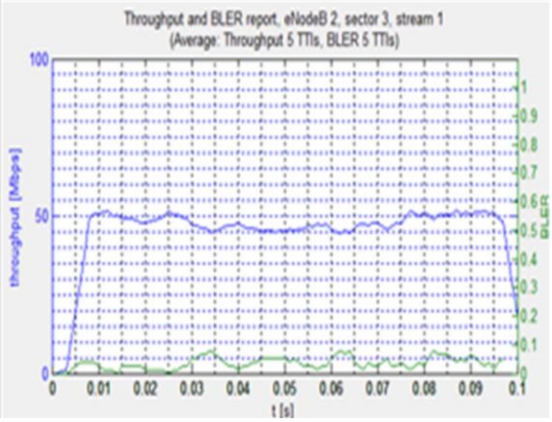

Figure 5 Average sector throughputs for two stationary users

It is clear from the simulation results presented above that high CQI values (low user speed) correspond to high SINR at the receiver (base station). This status suggests the assignment of fast modulation scheme in the downlink such as 64-QAM to accommodate high data rates. However, in low CQI (high mobility), the downlink falls back to 16-QAM or QPSK at lower SINR to reduce errors.

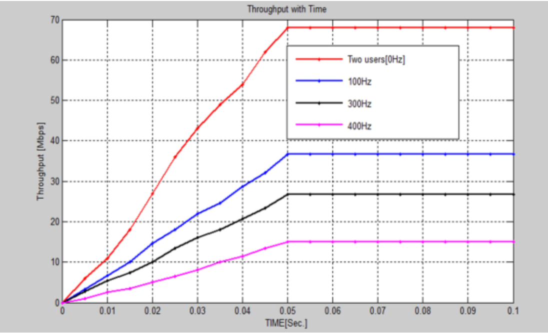

Figure 6. Average throughput for Doppler frequency (0, 100, 300, and 400 Hz).

The results also indicate that the proposed mapping scheme implies a nonlinear relation between CQI and SINR. The gain achieved by the proposed approach, can be illustrated from the data shown in Figures 2 and 3 as well as Table I. It is evident that for a UE with speed for which CQI is ranging from 5 at an SINR of 0.7 dB to CQI of 10 with a SINR of 10.3 dB, the eNB would choose the lower CQI leading to a 9.6 dB gain in terms of SINR.

6. CONCLUSION

In this paper a power-efficient CQI to SINR mapping scheme is proposed for LTE-A system operating in OLSM MIMO scheme which adapts to the minimum CQI for each user in downlink. We propose a nonlinear mapping of a range of CQI values to the SINR that minimizes the required power from the eNB as well as choosing the appropriate AMC that satisfies the QoS for UEs with different speeds.

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