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Channel Quality Information (CQI) Reporting Algorithms in LTE-A

Masturah Ahamad Sukor and Huda Adibah Mohd Ramli
Department of Electrical and Computer Engineering,
International Islamic University Malaysia (IIUM),
Kuala Lumpur, Malaysia

Abstract: Corresponding modulation and coding scheme will be selected by evolved Node B (eNodeB) through amplitude modulation and coding according to Channel Quality Information (CQI). This CQI is measured and estimated by User Equipment (UE) before being feedback to the eNodeB. In this study, the automated CQI reporting algorithm, the average CQI reporting algorithm and average RB-based (resource block) CQI reporting algorithm are being compared to see which algorithm is better in terms of producing reliable channel. The simulation results show that the average CQI reporting algorithm produced more compromising results than the automated CQI reporting algorithm and the average RB-based CQI reporting algorithm.

Key words: Modultion, codin, user equipment, feedback, algorithm

INTRODUCTION

The growing demand for higher data rates and improved Quality of Services (QoS) caused the collaboration in telecommunication associations named third Generation Partnership Program (3GPP to develop a project named Long Term Evolution-Advanced (LTE-A) (Akyildiz *et al*., 2010; Agilent Techonologies, 2011). LTE-A is aiming to achieve higher peak data rates (downlink peak data rate of 1Gbps and uplink peak data rate of 500 Mbps), packet-optimized, low-latency, secure service and increased capacity and coverage (Kottkamp, 2009; Juan and Roberto, 2014). LTE-A has to meet the requirements of International Mobile Tele communications-Advanced (IMT-Advanced) for the Fourth Generation (4G) technology in Release 10 in term of backward compatible enhancement of the legacy Long Term Evolution (LTE) Release 8 standard (Akyildiz *et al*., 2010; Agilent Techonologies, 2011). According to Akyildiz *et al*. (2010) the requirements for LTE-A included 2048 kbps for indoor application, 384 kbps for outdoor to indoor pedestrian environments, 144 kbps for vehicular connection and 9.6 kbps for satellite connection. LTE has taken over a global coverage of 10% with >260 operators with 44% of this deployments use the 1800 MHz band (Ramli *et al*., 2014).

Carrier Aggregation (CA) in LTE-A improves the peak data rates because it is capable to support much wider transmission bandwidth by aggregating a number of Component Carriers (CC)s of the same or different frequency bands (Akyildiz *et al*., 2010). Guaranteed Bit Rate (GBR) applications are more sensitive to packet delays and Non-Guaranteed Bit Rate (Non-GBR) applications are more sensitive to packet loss. This caused the packet scheduling to be essential in LTE-A since it uses packet switching technology in delivering multimedia packets according to (Ramli *et al*., 2014).

The LTE-A architecture consists of base stations called enhanced Node Bs (eNodeBs) which connects users to the core network and responsible to perform all Radio Rresource Management (RRM) functions (Ramli *et al*., 2009). Adaptive Modulation and Coding (AMC) is used by eNodeBs to select a corresponding modulation and coding scheme according to Channel Quality Information (CQI) reports which are estimated and feed backed by the User Equipment (UE) (Yuan *et al*., 2013). AMC is used in LTE system to adapt the channel variation and achieve high performance (Wu and Chu, 2011).

In (Cao *et al*., 2014; Lee *et al*., 2014) the researchers highlight the main parameters to deal with in improving the LTE and LTE-A. The researchers are investigating about the new elements to be considered for planning and designing of LTE networks oriented to QoS using Voice Over Internet Protocol (VoIP) in (Buenestado *et al*., 2014). The implementation of LTE-A as a global network is still new. The ability of LTE-A to attain higher peak data rates, packet-optimized, low-latency, secure service and increased capacity and coverage requires further performance study (Juan and Roberto, 2014). We are investigating two methods of channel quality indication reporting consists of automated CQI reporting algorithm and average CQI reporting algorithm in this study. Both methods are compared to observe which

Corresponding Author: Masturah Ahamad Sukor, Department of Electrical and Computer Engineering, International Islamic University Malaysia (IIUM), Kuala Lumpur, Malaysia

method is much more efficient in enhancing the LTE-A throughput. Video streaming packets is used as the multimedia application in this simulation tools. It is assumed to played back while streamed over variable bit rate mobile cellular channels.

MATERIALS AND METHODS

QI reporting algorithms: CA helps LTE-A to fully utilize the wider bandwidths up to 100 MHz while having backward compatibility with LTE. Intra-band contiguous CA, Intra-band Non-Contiguous CA and Inter-band Non-Contiguous CA are three types of CA for LTE-A. A number of adjacent CCs aggregated within the same frequency band using the Intra-band Contiguous CA while a number of CCs aggregated within the same frequency band in a non-contiguous manner using the Intra-band Non-Contiguous CA whereas a CA type that aggregates a number of Ccs of different frequency bands is Inter-band Non-Contiguous CA. Inter-band Non-Contiguous CA is more practical for use by the cellular operators because current mobile cellular spectrums are highly fragmented with large frequency separation (Akyildiz *et al*., 2010; Ramli *et al*., 2014).

The well-known random CC selection algorithm is implemented into the simulation tool to make CC selection as there are more than one CC available. In order to determine the selected user whose packets should be transmitted to each RB in the downlink LTE-A, the packet scheduling algorithm is used after a CC or a number of CCs assigned to the users (Ramli *et al*., 2014). Note that LTE user requires only one CC while LTE-A user requires a number of CCs. The general model of downlink LTE-A with CA is shown in Fig. 1.

The downlink LTE-A have a single cell with an eNodeB positioned in the middle of the cell and the users and uniformly positioned within the cell. Inter-band Non-Contiguous is used where the downlink LTE-A contains 2 CCs of 900 MHz (each CC is 3MHz bandwidth with 15 RBs) and 2 GHz carrier frequency. Each RB contains a total of 168 Resource Elements (REs) which majority are used to carry downlink data while the remaining are used for control and signaling purposes (Ramli *et al*., 2014).

Each sub-carrier in a single RB has 15 kHz spacing with minimum variations of multipath fading assumed. The instantaneous Signal-to-Interference-Noise-Ratio (SINR) of an RB and on a CC is computed on a subcarrier located at the centre frequency of the RB (Ramli *et al*., 2014) as follows:

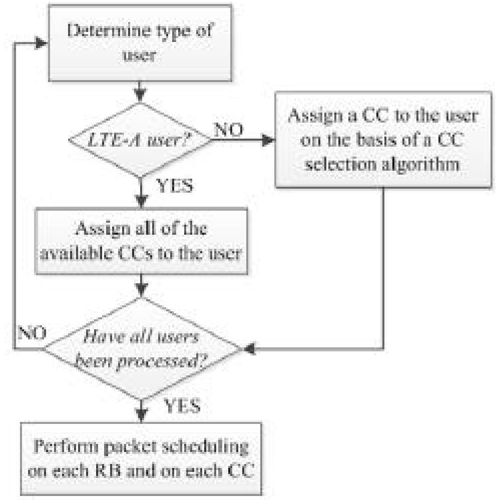

Fig. 1: A generalized model of the downlink LTE-A with CA (Ramli *et al*., 2014)

$$Y_{i,j,k}(t)=\frac{P_{total}\times gain_{i,j,k}(t)}{RB_{max}(1+N_0)} \quad (1)$$

$$gain_{i,j,k}(t)=10\left(\frac{pl_{ik}(t)}{10}\right)\times 10\left(\frac{\zeta_i(t)}{10}\right)\times 10\left(\frac{mpath_{i,j,k}}{10}\right) \quad (2)$$

where:

$\gamma_{i,j,k}(t)$	=	Is the instantaneous SINR (in dB) of user i on RB j on CC k at time t,
$mpath_{i,j,k}(t)$	=	Is the multi-path fading gain (in dB) of user i on RB j on CC k at time t,
$pl_{i,k}(t)$	=	Is the path loss (in dB) of user i on CC k at time t,
$\hat{\imath}_i(t)$	=	Is the shadow fading gain (in dB) of user i at time t,
P_{total}	=	Is the total eNB transmit power (in dBm),
Rb_{max}	=	the maximum available number of Rbs,
N_o	=	And the thermal noise (in watts) and I is the inter-cell interference (in watts) (assumed that inter-cell interference is constant as only one hexagonal cell considered)

The instantaneous Signal-to-Interference Noise Ratio (SINR) computed by the UE will be mapped into a CQI value before it being reported to the eNodeB. Each CQI value corresponds to the AMC (Ramli *et al*., 2009; Chen *et al*., 2011) . CQI report is also used to estimate the data rate of a user during data transmission. The instantaneous data rate can be computed as follows:

$$r_{ijk}(t) = \text{Effciency}_{ijk}(t)\frac{RE_{data}}{TTI} \quad (3)$$

Where:

Efficiency $_{i,j,k}$ (t) = The efficiency (in bits/RE) of RB j on CC k of user i at time t and

Re_{data} = The total number of REs specified for downlink data transmission

Automated CQI reporting algorithm: CQI is paramount for the data transmission which is used to select the most suitable modulation and coding scheme under the present channel conditions in 2011). In other words, AMC is dependent of the accurateness of feedback measurement for CQI. In this algorithm, the UE will automatically computed the value of CQI should be reported to eNodeB. Then, the CQI feedback is mapped to the previous CQI computed when the delay or error is presented by Ramli *et al*. (2011). The value of CQI report automated can be computed as follows:

$$\text{Automated CQI} = \text{CQI (i} - \text{Cqidelay)}_{i,j,k,1} \quad (4)$$

where, CQI(i-cqi delay)$_{i,j,k,l}$ is the CQI feedback mapped to previous CQI computed at time loop i on CC j of user at RB l and cqi delay is the delay on CQI reported.

Average CQI reporting algorithm: The general idea of average CQI reporting algorithm is to use average CQI reports for as CQI feedback for AMC to optimize the accurateness of the CQI report. In this algorithm, there are two types of CQI that will be reported by the UE; the estimated CQI computed by the UE (negligible delay) and actual CQI reported by the UE (includes the delay). The algorithm will then computed so that just one CQI average will be feed back to the eNodeB. This algorithm is expected to minimize the differentiation between the estimated CQI report and the actual CQI report. The average CQI reporting can be computed as follows:

$$\text{AverageCQI} = \frac{\text{CQI(estimated)}_{i,j,k,1} + \text{CQI(reported)}_{i,j,k,1}}{2} \quad (5)$$

where CQI(estimated)$_{i,j,k,l}$ is the CQI estimated by the at time loop i on CC j of user at RB l and CQI(reported)$_{i,j,k,l}$ is the actual CQI reported to the eNodeB at time loop i on CC j of user at RB l.

Performance evaluation: The reporting algorithm is to send only one average CQI report for every 15 resource blocks at one time. This algorithm is used with the purpose to save the power of the devices so that unnecessary transmission will not be executed. However, the algorithm is test to observe its performance. The average RB-based CQI reporting can be computed as follows:

$$\text{Average RB based CQI} = \frac{\text{CQI}_{(i,j,k,l)} + \text{CQI}_{(i,j,k,l,)+1} + \text{CQI}_{(i,j,k,l,)} + n}{15} \quad (6)$$

where maximum number of n is 14 and CQI$_{(i,j,k,l)}$ is the CQI reported by the at time loop i on CC j of user at RB l.

Performance evaluation: In this simulation, the performance of the algorithms are evaluated within 250 m radius for maximum of 61 users. The minimum user throughput is maintained above 469 kbps. The number of discarded packets are needed to minimize the delay violation for the GBR application. According to Kottkamp, (2009) and Ramli *et al*. (2014) the performances of the well-known algorithms are evaluated on the basis of the application-dependent Packet Loss Ratio (PLR) threshold and mean user throughput metrics that are defined as follows:

$$PLR = \frac{\sum_{i=1}^{N}\sum_{t=1}^{T} \text{pdiscard}_i(t)}{\sum_{i=1}^{N}\sum_{t=1}^{T} \text{psize}_i(t)} \quad (7)$$

$$\text{Mean user throughout} = \frac{1}{N}\frac{1}{T}\sum_{i=1}^{N}\sum_{t=1}^{T} \text{prx}_i(t) \quad (8)$$

Where:

$\text{pdiscard}_i(t)$ = The total size of discarded packets (in bits) of user i at time t, psize_i

(t) = The total size of all packets (in bits) arrive into the eNodeB buffer of i at time t,

$\text{prx}_i(t)$ = The total size of correctly-received packets (in bits) of user i at time t,

N = is the total number of users and T is the total simulation time

RESULTS AND DISCUSSION

The simulation is done using the C+ programming. Figure 2 shows the PLR performances of three CQI reporting algorithms with increasing system capacity. According to the 3GPP specification, the PLR value should not exceed 10^{-3}. So, the PLR should be kept below 10^{-3} threshold to meet the QoS requirement of the GBR application. Degradation of PLR occurs as there will be more packets waiting for downlink transmission at the eNodeB buffers with the increasing system capacity because the packets whose delay reached the buffer

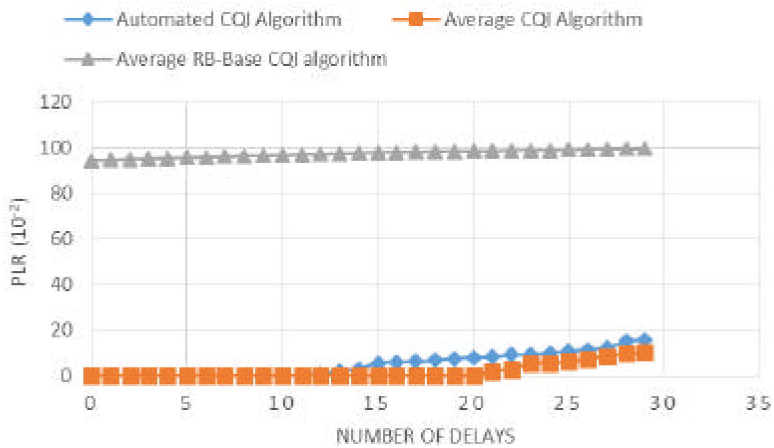

Fig. 2: The capacity comparison between three algorithms

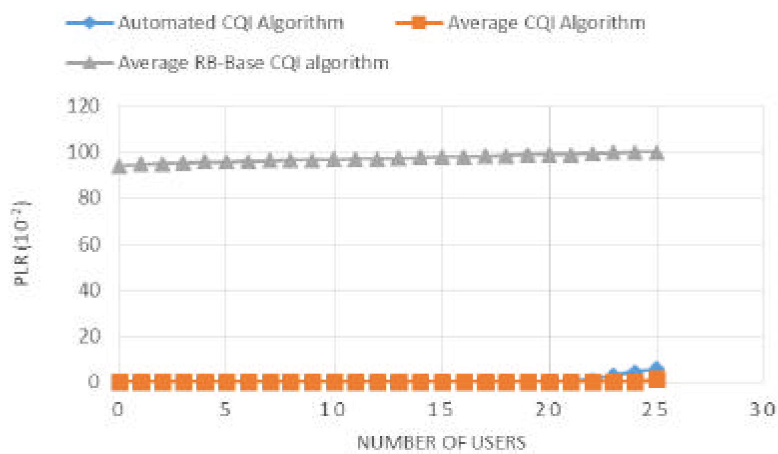

Fig. 3: The delay supported by the three algorithms

Table 1: Maximum system capacity supported by the algorithms to meet QoS requirements for GBR application

Algorithm	Max. system capacity	Improvement over Automated CQI (%)
Automated CQI	20	-
Average CQI	23	15
Average RB-based CQI	-	-100

Table 2: Maximum delay supported by the algorithm to meet QoS requirements for GBR application

Algorithm	Max. system capacity	Improvement over Automated CQI (%)
Automated CQI	11	-
Average CQI	18	63.64
Average RB-based CQI	-	-100

delay threshold will be discarded. Table 1 shows the maximum system capacity that meet the QoS requirement of GBR applications in Automated CQI algorithm is 20 and Average CQI algorithm is 23 but Average RB-base CQI algorithm.

Based on Fig. 2, it is shown that the Automated CQI algorithm can support up to 20 users and Average CQI algorithm can support to 23 users while the Average RB-based CQI algorithm unable to support any user at all if the minimum throughput of 469 kbps is required to be maintained. The Average RB-based CQI algorithm has the worst PLR performance as it cannot support any user. This is because the average RB-based CQI algorithm will transmit only one report for average RB as its main idea is to save power for unnecessary transmission. As for the Average CQI algorithm, it is able to increase the performance of the CQI reporting for about 15%.

On the second part of the simulation, the number of delay supported by the system as the PLR kept below 10^{-3} threshold to meet QoS requirement is shown in Table 2. Based on Fig. 3, the Average RB-based CQI algorithm still has the worst PLR performance as it cannot support delay for longer simulation while Automated CQI algorithm can support up to 11 delays and Average CQI algorithm can support to 18 delays. The average CQI algorithm is able to hold more delays as the CQI experienced by the users when a TB is received and the CQI that was used to determine the MCS for the TB before it was transmitted will be sum up for a higher user speed.

CONCLUSION

Three CQI reporting algorithms of LTE-A which are Automated CQI reporting algorithm, Average CQI reporting algorithm and Average RB-based CQI algorithm are being compared to observe which algorithm compromise a better performance in terms of PLR. The simulation results showed that the Automated CQI reporting algorithm produced more compromising results than the Average CQI reporting algorithm.

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