

A Novel CQI Calculation Scheme in LTE\LTE-A Systems

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Abstract—We propose a novel Channel Quality Indicator (CQI) calculation scheme in LTE\LTE-A systems. SNR-CQI mapping scheme, as well as SINR-CQI mapping scheme, is extensively studied in previous works. However, these kinds of CQI mapping schemes always provide imprecise results in fading channels, since all of them ignore the channel quality degeneration caused by other factors. In this paper, we further improve CQI calculation by considering the impact of multipath delay spread. The calculation scheme is presented in details. In order to guarantee the converge of CQI calculation, a Block Error Ratio (BLER) based converge algorithm is proposed. Simulations show that our calculation scheme can select CQIs more precisely, and achieve better throughput performance than traditional schemes. Furthermore, our scheme converges much faster than previous schemes.

Index Terms—CQI calculation, feedback, LTE\LTE-A.

I. INTRODUCTION

With the increasing demand of Quality of Service (QoS) in wireless communication system, more aggressive techniques are employed to improve the frequency and time efficiency. Adaptive Modulation and Coding (AMC) is one of the techniques that are applied in real systems to increase the throughput. By adaptively selecting the appropriate modulation order and coding rate, AMC can provide a much better system performance than fixed modulation and coding schemes. In order to conduct AMC operation in LTE\LTE-A systems (see [1], [2], [3]), Channel Quality Indicators (CQIs) need to be fed back by User Equipments (UEs) or Mobile Stations (MSs).

The calculation algorithms of CQI are numerous. Most of the previous works utilize the SNR-CQI mapping to determine CQIs. In [4], the SNR-CQI mapping is designed offline. Each UE estimates the channel state information (CSI), then extracts channel SNR and applies SNR-CQI mapping to determine CQIs. In this kind of CQI calculation algorithm, SNR is the only reference for CQI selection.

Based on SNR-CQI mapping algorithm, lots of enhanced schemes have been proposed. In [5], the author considers the CQI feedback in MU-MIMO systems. It is proposed that SINR-CQI mapping should be adapted instead of SNR-CQI mapping, since user interferences become a major challenge of channel quality. In [6], the authors propose a leakage-based precoding algorithm, so as to compute a more reliable CQI and minimize user interference. As a result, the computing algorithm of CQI is based on a SLNR-CQI mapping.

Unfortunately, all the above mappings are calculated in some fixed channel models (for examples, AWGN and Rayleigh channels). In different channel models, SNR-CQI mapping (as well as SINR-CQI and SLNR-CQI mappings) is different when comparing with itself. Consequently, all the above mappings are not perfectly suitable in realistic scenarios. A solution based on SNR conversion is proposed in [7]. The authors derive the conversion criterions to convert SNRs of other channel models into that of AWGN channel. Then CQIs of other channel models can be obtained by substituting the converted SNRs into AWGN channel's SNR-CQI mapping.

However, channel quality is not only decided by the quality of signal power. In [8], the authors present three kinds of factors that will cause CQI errors. Among them, mobility of UEs may be the most serious one. The impact of mobility in channel quality reflects on the size of multipath delay spread. The larger the spread is, the larger the transmission delay is, and the worst the channel quality becomes.

In order to deal with the CQI errors caused by multipath delay spread, we propose a novel CQI calculation algorithm: SNR&Delay-CQI mapping. This algorithm jointly utilizes SNR and maximum multipath delay spread (denoted as *Delay*) of instantaneous channel state, to achieve a much more precise CQI under fading channels. Moreover, we embed this SNR&Delay-CQI mapping into a BLER-based CQI converge algorithm, with the purpose of minimizing the impact of channel estimation errors. It is worth noticing that our scheme can be extended to large scale wireless networks [9] [10] [11] [12].

The rest of the paper is organized as followed. Section II provides a brief discussion on limitations of SNR-CQI mapping. Our SNR&Delay-CQI mapping is presented in details in Section III. Section IV describes the BLER-based CQI converge algorithm. Simulations can be seen in Section V. And we conclude the paper in Section VI.

II. SNR-CQI MAPPING AND ITS LIMITATION

In LTE\LTE-A system, UEs select CQIs according to the results of channel estimation. Actually, each CQI in LTE\LTE-A system is a pair of modulation order and coding rate. The detailed definition of CQI, as well as the mapping from CQI to each modulation order and coding rate pair, can be found in [3]. Each UE tries to find an optimal pair of modulation

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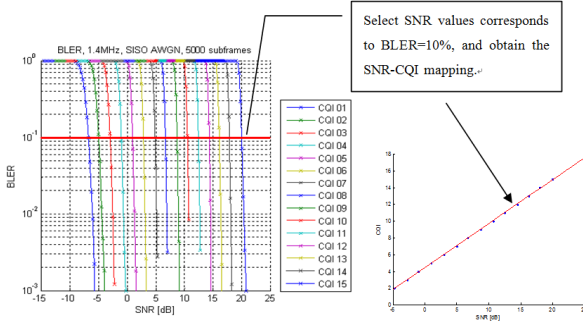


Fig. 1. SNR-CQI mapping generation in AWGN channel

order and coding rate, which provides the largest throughput when the BLER is less than 10 percent.

However, this process always costs too many computing resources for UEs. Therefore, simplifications of this optimizing process need to be adopted. Measurements and simulations should be conducted previously, so as to determine the optimal CQIs under different CSI conditions. After that, a CSI-CQI function or mapping is derived by a fitting of data. In this sense, UEs can obtain the feedback CQIs timely, as long as the channel estimations are finished.

Based on this idea, SNR-CQI mapping is proposed by many previous works. A common way to obtain a SNR-CQI mapping consists of three steps.

- In the first step, a BS employs CQI one by one in transmission. An active UE receives signals, then measures the SNR-BLER curve for each CQI, respectively. The UE preserves a group of SNR-BLER curves, each of which corresponds to a CQI.
- In the second step, UE selects the SNR value corresponding to BLER = 10% in each curve. Note that each curve corresponds to a CQI.
- In the third step, UE utilizes the SNR values selected in the second step, as well as the corresponding CQIs, to fit the desired SNR-CQI mapping.

An example of SNR-CQI mapping generation is showed in Fig. 1.

However, SNR is not the only parameter to determine a channel's quality. A SNR-CQI mapping in one channel model may fail to maintain a good performance in another. Fig. 2 presents the SNR-CQI mappings in some classic channel models. All the channel models are based on the measurements in realistic scenarios by 3GPP [3].

It is clear in Fig. 2 that one SNR value may correspond to different CQIs in different channel models. Such a difference is brought by a channel quality variation, which is a consequence of the variation of channel parameters other than SNR. Moreover, the SNR-CQI mappings plotted in Fig. 2 are achieved with the priori knowledge of channel models. In real systems, it is almost impossible to estimate the channel models in UEs. As a result, SNR-CQI mapping is incapable of achieving accurate CQI values.

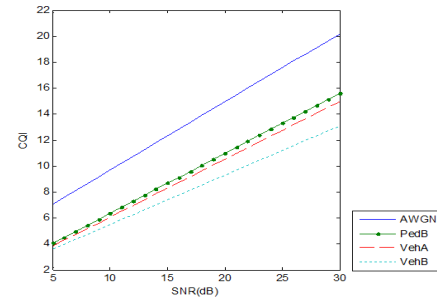


Fig. 2. SNR-CQI mappings in different channels

III. SNR&DELAY-CQI MAPPING

A. Certification for the Use of Multipath Delay Spread

Expect of SNR, multipath delay spread (denote as *Delay* for short) is another critical parameter in determining channel quality. Multipath delay spread is a measure of the multipath richness of a channel. It can be interpreted as the difference between the time of arrival of the first significant multipath component and the time of arrival of the last multipath component. In other words, it is the maximal delay of multipath transmissions. With the increase of *Delay*, more and more CQIs can not be adapted in transmissions even when SNR is high enough. Fig. 3 gives an illustration of invalid CQIs when *Delay* increases.

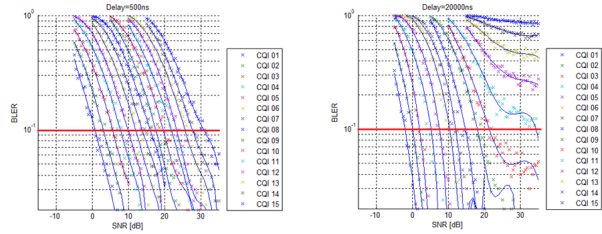


Fig. 3. Illustration of invalid CQIs when *Delay* increases. The left one presents the SNR-BLER curves for *Delay* = 500ns, and the right one stands for *Delay* = 20000ns

It can be seen from Fig. 3 that, when *Delay* is 500ns, all the 15 CQIs¹ can be used if SNR is large enough.² However, when *Delay* increases to 20000ns, only 10 CQIs can be used even maximum SNR is provided.

From the above analysis, we can conclude that multipath delay spread should be consider carefully in CQI calculation schemes.

B. Generation of SNR&Delay-CQI Mapping

In real systems, such as LTE/LTE-A systems and HSD-PA systems, there are too many factors affecting the system BLER. In order to obtain a SNR&Delay-CQI mapping,

¹Number of CQIs that are employed in LTE/LTE-A system is 15

²In real system, a SNR of 30dB is almost the largest SNR that can be achieved in optimal conditions. Correspondingly, we use 30dB as the upper value of SNR in this paper.

empirical formula should be achieved by simulations and measurements. In our work, we employ a link-level simulation platform³, which contains all the functions of LTE downlink transmissions, such as Turbo coding, linear MIMO decoding, channel estimation, AMC, etc. With the help of this platform, we adopt the following algorithm to obtain the SNR&Delay-CQI mapping in fading channels.

Algorithm 1 Generation of SNR&Delay-CQI Mapping

1. Set current *Delay* value D equals 0. Set measurement step of *Delay* as Δ_d .
2. Set current *Delay* value as $D + \Delta_d$, obtain the power delay profile of the corresponding channel [13].
3. Proceed transmissions in the channel generated in step 2, and obtain a SNR-CQI mapping as described in Section II.
4. If current *Delay* value is larger than the max value of *Delay* in measurement process, go to step 5. Otherwise, repeat step 2 and step 3.
5. Obtain a group of SNR-CQI mappings corresponding to different *Delay* values, and fit these mappings into a 3-dimension function:

$$CQI = F(SNR, Delay)$$

6. Output F .
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C. A Simplified but Effective SNR&Delay-CQI Mapping

The process of calculating a 3-dimension function $CQI = F(SNR, Delay)$ by Algorithm 1 is complex. And the storage of such a function is relatively large in mobile devices. Here we present a simplified scheme, which changes the 3-dimension function $CQI = F(SNR, Delay)$ into a piecewise function. We will prove the effectiveness of such a simplified scheme in Section V. The cut-off points of the piecewise function in *Delay* axis defined as followed:

Definition 1: (CQI i 's cut-off point) The *Delay* cut-off point of CQI i represents the maximal multipath delay spread, under which the corresponding BLER is within system's limit while the largest SNR condition is provided.

In other words, the increase of multipath delay spread will cause a decrease of the available CQIs, since channel quality drops largely and can no long sustain high level modulations or coding rates. The turning points of available CQIs in multipath delay spread axis are defined as the cut-off points. A multipath delay spread that is larger than the cut-off point of CQI i will result in a large BLER by CQI(s) larger than i . A graphical illustration of cut-off points is presented in Fig. 4.

We propose to use the following cut-off points in LTE\LTE-A systems.

$$Q_{max} = \begin{cases} 15 & D \geq 400ns \ (D_{15}) \\ 14 & 400ns < D \leq 9500ns \ (D_{14}) \\ 13 & 9500ns < D \leq 12500ns \ (D_{13}) \\ 12 & 12500ns < D \leq 14800ns \ (D_{12}) \\ 11 & 14800ns < D \leq 18000ns \ (D_{11}) \end{cases} \quad (1)$$

³This simulation platform is developed by IWCT, Shanghai Jiao Tong University.

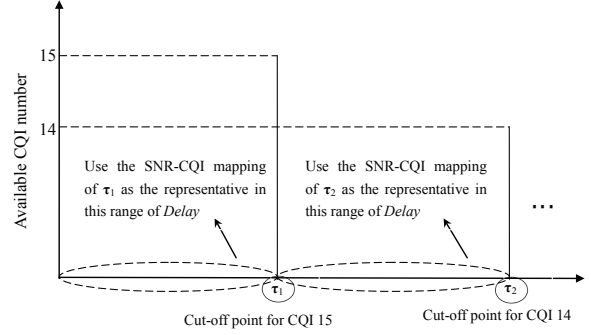


Fig. 4. A graphical interpretation of cut-off points and their meanings. A cut-off point is the maximal multipath delay spread that a certain CQI can be used with an optimal SNR condition.

where Q_{max} is the maximal CQI that can be used within two *Delay* cut-off points, and D denotes the *Delay*. D_{15} to D_{11} denote corresponding *Delay* range for short.

The corresponding piecewise function for SNR&Delay-CQI mapping is:

$$Q = \begin{cases} \min(\lfloor 0.513S - 0.215 \rfloor, 15) & D \in D_{15} \\ \min(\lfloor 0.431S + 2.148 \rfloor, 14) & D \in D_{14} \\ \min(\lfloor 0.402S + 2.152 \rfloor, 13) & D \in D_{13} \\ \min(\lfloor -0.004S^2 + 0.513S + 1.74 \rfloor, 12) & D \in D_{12} \\ \min(\lfloor -0.007S^2 + 0.527S + 1.77 \rfloor, 11) & D \in D_{11} \end{cases} \quad (2)$$

where Q represents the selected CQI, $\lfloor \cdot \rfloor$ denotes the rounding-down calculation, and S is the channel SNR.

It is worth pointing out that although the above results are achieved based on the simulations, they can be applied in most of the scenarios in LTE systems. First of all, all the simulations are conducted under typical LTE/LTE-A scenarios. Secondly, any CSI-CQI mapping is a rough estimation, which can be refined by the following converge algorithm. Moreover, the above scheme can be reapplied in other scenarios or systems with similar simulations and measurements.

IV. BLER-BASED CQI CONVERGE ALGORITHM

There are multiple factors that will decrease the performance of SNR&Delay-CQI mapping described in Section III. The accuracy of CQI calculation will be disturbed by the times and granularity of measurement, as well as the selection of simulation channels. As a result, UEs may select inappropriate CQIs over and over again. In order to guarantee a relatively good accuracy of CQI calculation, a BLER-based CQI converge algorithm is proposed. The SNR&Delay-CQI mapping is nested inside the body of BLER-based CQI converge algorithm. Every selected CQI will be re-evaluated by BLER-based CQI converge algorithm, so as to maintain a BLER that fits the system's requirement.

If channel quality decreases, the feedback CQI should decrease, or at least remain the same. Therefore, we employ a CQI-decreasing function to make sure that feedback CQIs converge. The cut-off points decreased in (1) are used in

such a function. The CQI-decreasing function is presented as followed.

$$Q_{conv} = Q_{pre} - \Delta Q \quad (3)$$

and
 $\Delta Q =$

$$\begin{cases} [18.69\beta - 18.22\Delta\beta] & D \in D_{15} \\ [13.38\beta - 14.31\Delta\beta] & D \in D_{14} \\ [-93.55\beta^2 + 110.41\beta - 35.23\Delta\beta] & D \in D_{13} \\ [-123.67\beta^2 + 146.63\beta - 45.54\Delta\beta + 0.32] & D \in D_{12} \\ [-0.52\beta^2 + 35.59\beta - 34.64\Delta\beta - 0.1] & D \in D_{11} \end{cases} \quad (4)$$

where Q_{conv} denotes the converged CQI, Q_{pre} is the CQI fed back in previous period, ΔQ denotes the decreasing value to obtain a converged CQI value, β represents current BLER, and $\Delta\beta$ is the subtraction between BLER in the last period and BLER in the current period.

Based on the above function, the BLER-based CQI converge algorithm is presented in Algorithm 2.

Algorithm 2 BLER-based CQI Converge Algorithm

Input: Feedback CQI Q_{pre} , BLER β , SNR S_{pre} and Delay D_{pre} in the last transmission period, system threshold of BLER δ , current SNR S and Delay D .

Output: Refined CQI Q .

1. Initiate two intermediate variables $Q_1 = Q_2 = 15$.
 2. If $\beta \leq \delta$, go to step 5. Otherwise, go to step 3.
 3. If $S > S_{pre}$ and $D < D_{pre}$, go to step 5. Otherwise, go to step 4.
 4. Calculate converged CQI by equation(3), and save it in Q_1 .
 5. Calculate mapping CQI by equation(2), and save it in Q_2 .
 6. Output $Q = \min(Q_1, Q_2)$.
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By employing Algorithm 2, a refined CQI that can guarantee a BLER under system's threshold can be achieved conveniently.

V. SIMULATIONS AND DISCUSSIONS

In this section, we provide some simulation results to verify our SNR&Delay-CQI mapping and BLER-based CQI converge algorithm. In our simulations, we assume that the initial CQI in simulations is 15, so as to illustrate the converge process of CQIs. Channel models in [13] are adopted.

We denote our scheme as Scheme 1, which utilizes both SNR&Delay-CQI mapping and BLER-based CQI converge algorithm. The SNR-CQI mapping scheme proposed in [4], [7], etc, can not guarantee a converge on feedback CQIs. Therefore, we combine the SNR-CQI mapping and our BLER-based CQI converge algorithm to form Scheme 2. Scheme 3 represents the scheme that only employs a traditional dichotomous BLER-based CQI converge algorithm [1].

A. Comparison of CQI Converge Time

In order to compare the converge time for each scheme, we assume that the channels remain unchanged during simulation time. This setting is reasonable in slow fading channels. However, the simulation results can still provide a certification

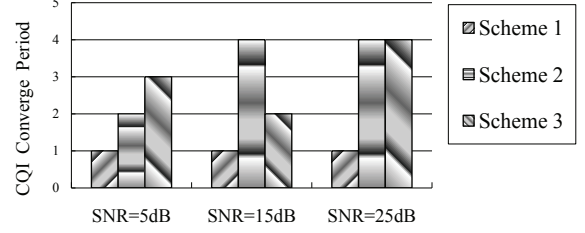


Fig. 5. Comparison of converge time in *PedB* channel

in fast fading channels (We will discuss in the following paragraphs).

Fig. 5 shows the comparison of CQI converge time in *PedB* channel [13]. *PedB* channel is a channel model characterizing the channel of pedestrians. The speed of mobile UEs is relatively small.

It is demonstrated in Fig. 5 that our scheme can converge at the final CQI with only 1 feedback period. Recall that we set the initial CQI as 15 in simulations, a converge period of 1 indicates that our scheme always selects a converged CQI in each feedback period. Other schemes consume up to 4 feedback periods to obtain a converged CQI. This means that other schemes require several feedback periods of interaction to finish CQI selection. This further illustrates that the scheduling overhead of our scheme is much less than that of the other two. Moreover, if the variation of channel is fast, our scheme can provide a real-time CQI calculation, while other schemes fail to catch up with the channel's variation.

Fig. 6 shows the comparison of CQI converge time in *VehB* channel [13]. *VehB* channel is a channel model characterizing the channel of vehicles. The multipath delay spread is much larger than that of *PedB* channel.

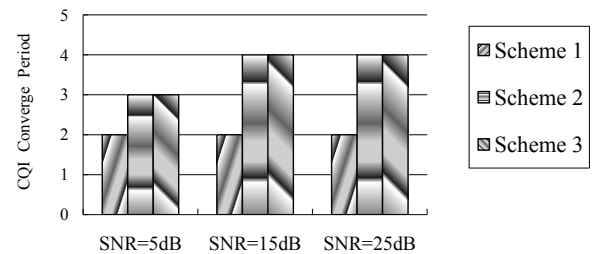


Fig. 6. Comparison of converge time in *VehB* channel

It can be seen that, with the increase of multipath delay spread, the channel quality decreases largely. As a result, it takes 2 feedback period for our scheme to calculate a converged CQI. The decrease in performance of our scheme is a consequence of more complex channel conditions in channels with large multipath delay spread. This only happens in the communications of high speed users (such as users in highways or subways). Although our scheme consumes more

feedback periods in *VehB* channel than in *PedB* channel, it still outperforms the other two schemes.

B. Comparison of Throughput

When comparing the throughput of the three schemes, we adopt the same assumption described in the beginning of Section V-A. The simulated SNR values are 5dB, 15dB and 25dB.

Fig. 7 presents the comparison of average throughput in *PedB* channel.

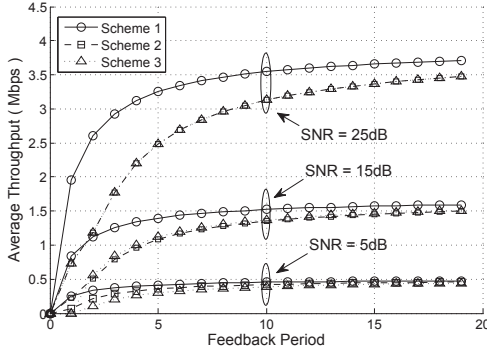


Fig. 7. Comparison of average throughput in *PedB*

Recall the assumption that initial CQI equals 15, the resulting throughput in the first transmission period (before a new CQI is fed back to BS) is almost zero, since the channel quality is far too poor to sustain the high modulation order and coding rate denoted by CQI 15. Consequently, the curves of average throughput starts from zero. However, it is still obvious from Fig. 7 that our scheme can always achieve a better throughput performance than other schemes. Moreover, our scheme reaches to the ultimate throughput much more quickly, which indicates that our scheme calculates CQIs more accurately and rapidly.

Fig. 8 shows the comparison of average throughput in *VehB* channel. It presents an interesting phenomenon: the achievable throughput (after a certain feedback periods) by different schemes are different. Our scheme provides the largest achievable throughput. It is well-known that downlink throughput in an AMC system is directly determined by the accuracy of CQI calculation. This phenomenon indicates that our scheme can select the optimal CQI, while other schemes only converge to a sub-optimal CQI. Hence, other schemes can not achieve the optimal throughput as our scheme.

VI. CONCLUSION

In this paper, we propose a novel CQI calculation scheme based on channel estimation. Unlike schemes proposed in previous works, our scheme not only considers the effect of SNR, but also takes multipath delay spread into account. A SNR&Delay-CQI mapping algorithm is designed to implement this idea. Furthermore, we nests this algorithm into a BLER-based CQI converge algorithm, so as to guarantee the

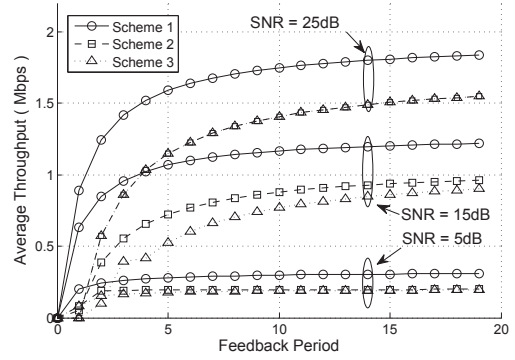


Fig. 8. Comparison of average throughput in *VehB*

converge of CQI calculation. Simulation results show that our scheme can select CQIs much more precisely and rapidly than previous schemes. Moreover, systems implementing our scheme can achieve a better average throughput. The design is based on LTE/LTE-A systems, but it can be applied directly on other systems.

VII. ACKNOWLEDGMENT

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