
Agenda Item: 7.2.4.1
Source: Huawei, HiSilicon
Title: CQI/MCS table design for 256QAM
Document for: Discussion and decision

1 Introduction

In RAN#62, the following objective was agreed for Small Cell Enhancements work item [1]:

- Spectrum efficiency enhancement with introduction of higher order modulation, i.e., 256QAM, in the downlink transmission, while keeping existing size of CQI feedback field and MCS indication.

In this contribution, we briefly review the principles of CQI/MCS table design in previous releases. Then the analysis and proposals for the new CQI/MCS table are provided to support 256QAM.

2 Principles and proposals for CQI/MCS design

2.1 CQI table design

The CQI table is used to support downlink adaptive modulation and coding. The design principles for the current CQI table are summarized as below [2] [3][4]:

- AWGN channel is assumed for generating the CQI table
- 15-entry CQI table with approximately equal step size in equivalent SNR
 - o It starts with -7dB as the 1st point and the spacing is 1.892 dB, thus the SNR range is [-7, 19.488]dB
 - o CQI index#1 with spectral efficiency = 0.1523 is used for PDCCH only
- The modulation order switching points in the CQI table should consider the frequency selectivity
 - o The modulation order switching points (i.e., QPSK to 16QAM and 16QAM to 64QAM) are determined by further evaluating the MCSs in the frequency selective channel. As is usually observed in the OFDM transmission, it is desirable to replace a few entries having lower modulation order and higher code rate by those having higher modulation order and lower code rate for an improved performance in the frequency selective channel.

Having the above principles in mind, the analysis and considerations for new CQI entry design with the introduction of 256QAM are discussed in this sub-section.

Figure 1 shows the simulation results of spectral efficiency vs. SNR with different modulation order and coding rate in AWGN channel (BLER=0.1).

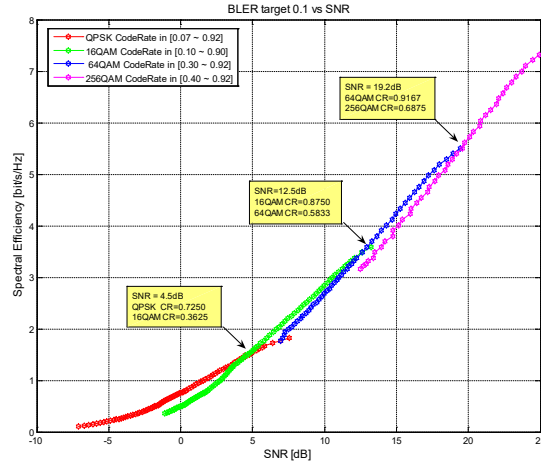


Figure 1. Spectral efficiency vs. SNR when BLER is 0.1

New CQI entries to support 256QAM

In order to support 256QAM transmission, the maximum efficiency of the current CQI table needs to be expanded. Since the maximum efficiency supported by current CQI table is 5.5547, the introduction of 256QAM can directly increase the efficiency to $5.5547 \times 8/6 = 7.4063$. The corresponding SNR where the spectral efficiency of 256QAM starts to saturate is around 25dB.

Following the previous principle, the CQI entries for 256QAM could be determined using an equal step size in equivalent SNR between 5.5547 and 7.4063. Since the curve of efficiency vs. SNR is almost linear in Figure 1, the new CQI entries for 256QAM could be samples based on approximately equal step size in spectral efficiency. For example, if 3 new CQI entries are introduced for 256QAM, the efficiency corresponding to each entry is 6.1719, 6.7891 and 7.4063. It is noted that the SNR step of the three new CQI entries is similar to the previous space size of 1.892dB due to the linearity of efficiency vs. SNR curve.

Proposal 1-1:

- **The maximum efficiency for 256QAM CQI entry is $5.5547 \times 8/6 = 7.4063$**
- **Three new CQI entries are introduced for 256QAM, the efficiency corresponding to each entry is 6.1719, 6.7891, 7.4063**

CQI index	Modulation	Code rate $\times 1024$	efficiency
13	256QAM	790	6.1719
14	256QAM	869	6.7891
15	256QAM	948	7.4063

Range of CQI region

With non-full buffer traffic, a cell edge UE may also benefit from 256QAM if the interfering cells are light-loaded or even turned off due to the traffic variation. This implies that the experienced SINR of a 256QAM UE may fluctuate in a large region in an interference limited scenario. Figure 2 shows typical CQI distribution of all UEs that using 256QAM in scenario 2b (sparse). Tx/Rx EVM is assumed as 4% and 2%. RU is about 30%. Other simulation assumptions are the same as [6]. It can be observed that the SNR region of out of range & QPSK have considerable chance to be scheduled (~12%) for 256QAM UEs. Therefore, CQI table for 256QAM should still reserve some entries for the low SNR region.

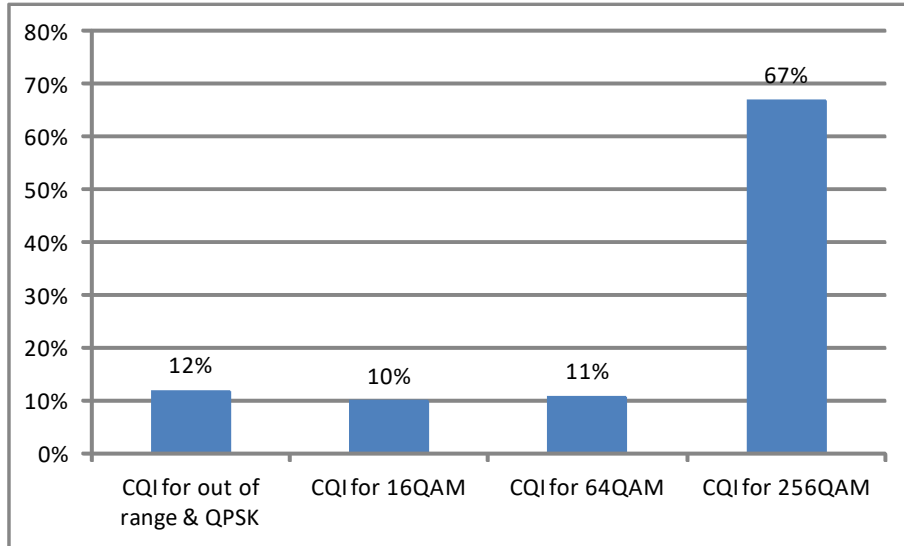


Figure 2: PDF of typical CQI distribution.

Since three new CQI entries are introduced for 256QAM transmission, three lower entries need to be removed to keep the table size as before. CQI index #0 should be reserved for out of range indication. CQI index #1 should be reserved for PDCCH transmission and downlink power control. CQI index #2 should also be reserved since it corresponds to the $I_{MCS}=0$ in the MCS table, which is the starting point of the interpolation of spectral efficiencies for the following MCS entries. Thus, one possibility is to remove the current CQI entries #3, #5 and #7. Other CQI entries should be remained unchanged in order to save standards effort in the following MCS and TBS table designs.

There are proposals to enlarge the CQI range to include 256QAM, e.g., [-7dB, 25dB], where each entry has approximately equal, but larger step size in equivalent SNR. This method requires totally new design of the CQI entries, and would result in the new design of the entire MCS and TBS tables, which is a significant standard effort and is therefore undesirable.

Proposal 1-2:

- **CQI table for 256QAM should reserve some entries for low SNR region**
 - **Current CQI entries #0, #1 and #2 should be reserved**
 - **Current CQI entries #3, #5 and #7 can be removed**
- **Other CQI entries should be reserved**

Switching point design of 64QAM and 256QAM

As summarized in the beginning of the section, the modulation order switching points in the CQI table should consider frequency selectivity. Thus we provide the link level simulations in Figure 3 and Figure 4 to evaluate the BLER of the same spectral efficiency with rank 1 and rank 2, respectively, but with different modulation order and coding rate in the EPA channel to find a reasonable switching point between 64QAM and 256QAM. CQI=14.5 means an average spectral efficiency of CQI index 14 and CQI index 15.

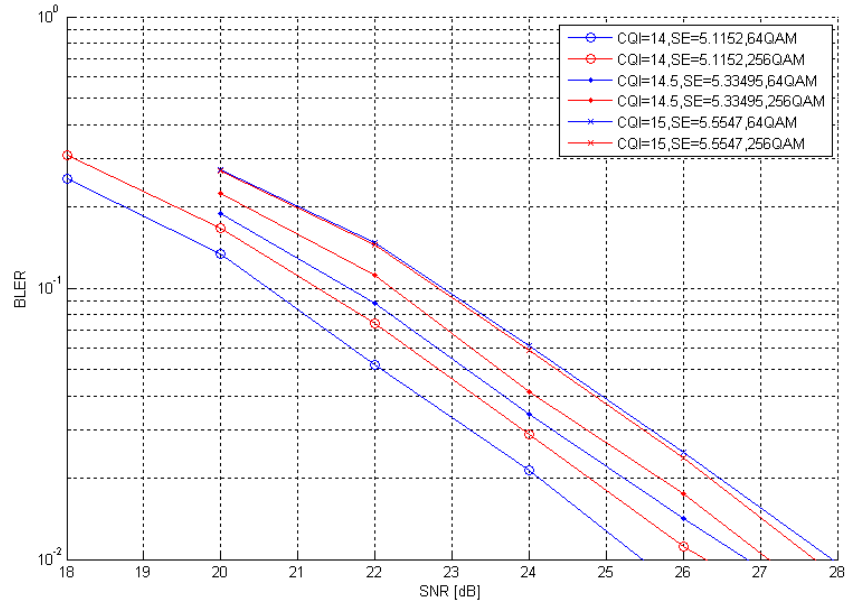


Figure 3: 64QAM/256QAM BLER comparison of the same spectral efficiency in the EPA channel with rank 1

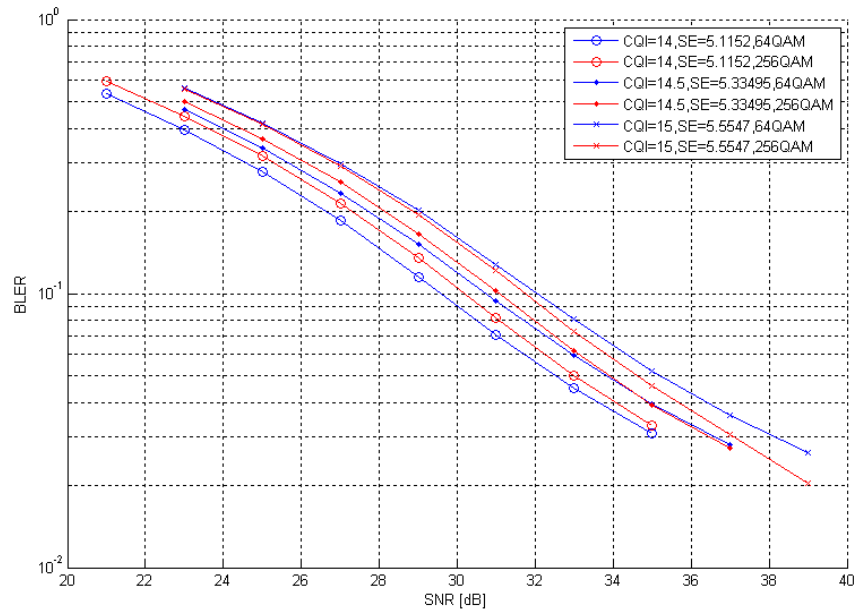


Figure 4: 64QAM/256QAM BLER comparison of the same spectral efficiency in the EPA channel with rank 2

It is observed that the spectral efficiency of 5.33495 for 64QAM outperforms 256QAM, while the spectral efficiency of 5.5547 for 256QAM outperforms 64QAM. Thus the switching point of 64QAM and 256QAM spectral efficiency should be lower than 5.5547.

The spectral efficiency of CQI index 15 in the current table is 5.5547, thus 256QAM will outperforms 64QAM in a frequency selective channel. It is therefore proposed that the modulation scheme of CQI index 15 is changed to 256QAM, while the spectral efficiency value could be maintained to reduce impact on MCS/TBS tables.

Proposal 1-3:

- **The modulation order of CQI index 15 is changed to 256QAM**
 - **The spectral efficiency could be maintained to reduce impact on MCS/TBS tables**

An example based on the above principles is shown as Table 1:

Table 1: Proposed 4-bit CQI table for 256QAM

CQI index	CQI index in current table	Modulation	Code rate x 1024	Efficiency
0	0	out of range		
1	1	QPSK	78	0.1523
2	2	QPSK	120	0.2344
3	4	QPSK	308	0.6016
4	6	QPSK	602	1.1758
5	8	16QAM	490	1.9141
6	9	16QAM	616	2.4063
7	10	64QAM	466	2.7305
8	11	64QAM	567	3.3223
9	12	64QAM	666	3.9023
10	13	64QAM	772	4.5234
11	14	64QAM	873	5.1152
12	15	256QAM	711	5.5547
13	-	256QAM	790	6.1719
14	-	256QAM	869	6.7891
15	-	256QAM	948	7.4063

2.2 MCS table design

The design principles for the current MCS table are summarized as below [4]:

- A 5-bit MCS table with 3 reserved entries for modulation order signaling
- CQI values taken as starting point for design
 - o 14 out of the 15 CQI values appear in the CQI table, i.e., CQI index 2~15
- Two MCSs defined in the overlap region ($r=0.66$ QPSK and $r=0.33$ 16QAM) and ($r=0.64$ 16QAM and $r=0.43$ 64QAM)
- The remaining 13 MCS entries chosen as equally spaced between adjacent spectral efficiencies.

As described above, the spectral efficiency of each MCS/TBS entry can be mapped to CQI entry as in Table 2, along with the corresponding spectral efficiency. According to the design in Table 1, current CQI entries #3, #5 and #7 are removed, thus the 7 MCS entries interpolated by #3, #5 and #7 need to be removed, which are marked as yellow below. The MCS/TBS entries mapped to CQI entries #3, #5 and #7 are maintained in order to avoid the redesign of TBS table.

Table 2: Map of current MCS/TBS entries to CQI index

MCS Index I_{MCS}	Modulation Order Q_m	TBS Index I_{TBS}	CQI index	Spectral efficiency
0	2	0	2	0.2344
1	2	1		0.3057
2	2	2	3	0.3770
3	2	3		0.4893
4	2	4	4	0.6016
5	2	5		0.7393
6	2	6	5	0.8770
7	2	7		1.0264
8	2	8	6	1.1758
9	2	9		1.3262
10	4	9		1.3262
11	4	10	7	1.4766
12	4	11		1.69535
13	4	12	8	1.9141
14	4	13		2.1602
15	4	14	9	2.4063
16	4	15		2.5684
17	6	15		2.5684
18	6	16	10	2.7305
19	6	17		3.0264
20	6	18	11	3.3223
21	6	19		3.6123
22	6	20	12	3.9023
23	6	21		4.21285
24	6	22	13	4.5234
25	6	23		4.8193
26	6	24	14	5.1152
27	6	25		5.33495
28	6	26	15	5.5547
29	2	reserved		
30	4			
31	6			

With the introduction of 256QAM, 7 MCS entries (i.e., I_{TBS} #27~#33) need to be added to reflect the corresponding efficiency or interpolated efficiency for the proposed CQI index #12-#15 for 256QAM. Moreover, the previous MCS entry corresponding to I_{TBS} #26 needs to be removed since the modulation type has been changed to 256QAM and the previous value is no longer applicable.

As shown in Figure 1, the switching point of 64QAM and 256QAM spectral efficiency is about 5.55 in an AWGN channel. The spectral efficiency of MCS entry corresponding to I_{TBS} #25 is 5.33495, and the spectral efficiency of MCS entry corresponding to I_{TBS} #27 is 5.5547. According to the switching point of 64QAM and 256QAM spectral efficiency in AWGN channel and EPA channel, the modulation scheme of MCS entry corresponding to I_{TBS} #27 should be 256QAM and the modulation scheme of MCS entry corresponding to I_{TBS} #25 should be 64QAM, no matter in AWGN channel or EPA channel. Therefore, there is no need to define overlap entry for 64QAM/256QAM.

Another MCS entry is needed for 256QAM retransmission, as the other modulation order.

Proposal 2:

- Define 8 MCS entries for 256QAM

- 7 MCS entries (i.e., I_{TBS} #27~#33) reflect the corresponding efficiency or interpolated efficiency for the proposed CQI index #12-#15 for 256QAM.

- 1 MCS entry for 256QAM retransmission
- 8 entries in Rel-8 MCS table should be dropped
 - 7 MCS entries (i.e., I_{TBS} #1, 3, 5, 7, 9, 9, 11) if the previous CQI entries #3, 5, 7 are dropped
 - 1 MCS entry (i.e., I_{TBS} #26) if the modulation order of CQI index #15 is changed to 256QAM
- Other MCS/TBS entries should be remained unchanged

An example based on above principles is shown as Table 3, where the TBS entries are defined in [7].

Table 3. Proposed 5-bit MCS table for 256QAM

MCS Index I_{MCS}	MCS Index I_{MCS} in current table	Modulation Order Q_m	TBS Index I_{TBS}
0	0	2	0
1	2	2	2
2	4	2	4
3	6	2	6
4	8	2	8
5	11	4	10
6	13	4	12
7	14	4	13
8	15	4	14
9	16	4	15
10	17	6	15
11	18	6	16
12	19	6	17
13	20	6	18
14	21	6	19
15	22	6	20
16	23	6	21
17	24	6	22
18	25	6	23
19	26	6	24
20	27	6	25
21	-	8	27
22	-	8	28
23	-	8	29
24	-	8	30
25	-	8	31
26	-	8	32
27	-	8	33
28	29	2	reserved
29	30	4	
30	31	6	
31	-	8	

2.3 Signaling for 256QAM

It was agreed in [6] that “Higher layer signalling is used to configure CQI/MCS table and/or 256QAM”. When considering carrier aggregation or dual connectivity between macro and small cell layer, it might be a common case that different carriers/cells would be configured with different CQI/MCS tables. The same situation might happen in CoMP scenarios when different transmission points might have different modulation configurations due to the channel and interference environment variation.

Proposal 3:

- **CQI/MCS table and/or 256QAM is configured by higher layer signaling per CC and transmission point.**

3 Conclusions

In this contribution, standard impacts to support 256QAM are analyzed, and the proposals are summarized as follows.

Proposals for CQI table:

- The maximum efficiency for 256QAM CQI entry is $5.5547 \times 8/6 = 7.4063$;
- Introduce three new CQI entries for 256QAM
 - o The efficiency corresponding to each entry is 6.1719, 6.7891, 7.4063
- CQI table for 256QAM should reserve some entries for low SNR region
 - o Current CQI entries #0, #1 and #2 should be reserved
 - o Current CQI entries #3, #5 and #7 can be removed
- The modulation order of CQI index 15 is changed to 256QAM
 - o The spectral efficiency could be maintained to reduce impact on MCS/TBS table
- Other CQI entries should be remained unchanged

Proposals for MCS table:

- Introduce 8 MCS entries for 256QAM
 - o 7 MCS entries (i.e., I_{TBS} #27~#33) reflect the corresponding efficiency or interpolated efficiency for the proposed CQI index #12~#15 for 256QAM.
 - o 1 MCS entry for 256QAM retransmission
- 8 entries in Rel-8 MCS table should be dropped
 - o 7 MCS entries (i.e., I_{TBS} #1, 3, 5, 7, 9, 9, 11) if the previous CQI entries #3,5,7 are dropped
 - o 1 MCS entry (i.e., I_{TBS} #26) if the modulation order of CQI index #15 is changed to 256QAM
- Other MCS/TBS entries should be remained unchanged

Proposals for signaling:

- CQI/MCS table and/or 256QAM is configured by higher layer signaling per CC and transmission point

The examples of CQI and MCS tables for 256QAM are provided in Table 1 and Table 3.

References

- [1] RP-132073, "New WI proposal: Small cell enhancements - Physical layer aspects", Huawei, CATR, HiSilicon, RAN#62, Dec. 3-6, 2013.
- [2] R1-075069, "Summary of Ad Hoc session on 6.4.5", Ad Hoc Chairman, RAN1#51, Nov. 5-9, 2007.
- [3] RAN1 Reflector Discussion on LTE CQI, "4-bit CQI Proposal", Nokia Siemens Networks, Nokia, Dec. 2007.

- [4] R1-081638, “TBS and MCS Signaling and Tables”, Motorola, RAN1 #52b, Mar. 31-Apr. 4, 2008.
- [5] R1-080049, “Summary of email discussion on CQI reporting”, Samsung, Jan. 14-18, 2008.
- [6] 3GPP TR 36.872, “Small cell enhancements for E-UTRA and E-UTRAN Evaluation assumptions for small cell enhancements- Physical layer aspects”, v12.0.0, Sept. 2013.
- [7] R1-140035, “TBS table design for 256QAM”, Huawei, HiSilicon, RAN1#76, Feb. 10-14, 2014.

Appendix

Table 4: Link level simulation assumptions

Bandwidth	10MHz
Carrier frequency	2GHz
Channel model	AWGN, EPA
Transmission mode	TM4
MIMO configuration	1x1 for AWGN 2x2 with low correlation for EPA
CRS configuration	Antenna ports 0,1
Rank adaptation	Fixed as 1 or 2
Link adaptation	Off
HARQ	Off
UE receiver	MMSE-IRC
Channel estimation	ideal
Interference estimation	ideal
PDP estimation	ideal
Received timing delay (us)	0
Frequency offset (Hz)	0
UE speed	3km/h
Data Allocation	4 RBs
Channel coding	Turbo
Overhead assumption	3 PDCCH symbols;
	2-port CRS;