**3GPP TSG-RAN WG1 NR R1-1706176**

**Spokane, USA, 3th– 7thApr 2017**

**Agenda item:** **8.1.4.1.2**

**Source: Mediatek Inc.**

**Title: QC-LDPC performance comparisons**

**Document for:** **Discussion/Decision**

# Introduction

In R1-88 meeting, there was a conclusion relating to the evaluation of performance.

**Conclusion:**

* Minimum set of information block sizes granularity for evaluation at BLER 1e-2 and 1e-4:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | 528<=K<=1024Ȑ | 1056<=K<=2048i | 2048<=K<=6144 | 6144<=K<=8192 |
| 8 | 16 | 32 | 64 | 128 |

* Some off-grid values of K shall also be evaluated.
* Minimum information block size for evaluation = 40

In this contribution, we do comparison on both performance for the proposed LDPC codes in [1], [3] and [4].

# Performance Comparisons with Proposed QC-LDPC Code A

It was noted by NTT DoCoMo in [1] that there is very little to separate different LDPC proposals based on performance alone and that some other criteria should be considered to separate competing designs. In this section, we try to show that the QC-LDPC code A proposed by Mediatek in [2], although compact in design, has performance equally as good, sometimes better, than any other proposed QC-LDPC code. The error count definition used is the same as LTE which early terminates the decoding when message bits are correct.

## Required SNR at BLER=1e-2 Performance Comparisons

In the following figures, we try to compare the required SNR at BLER=1e-2 among different proposals of a QC-LDPC code. As can be seen in the figures below, the proposed compact QC-LDPC code can achieve competitive performance at BLER=1e-2.

The blue line is for the proposed QC-LDPC code A in [2] by Mediatek using a 50-iter-Flooding-SP decoder.

The red line is for the proposed QC-LDPC code in [3] also using a 50-iter-Flooding-SP decoder.

The green line is for the proposed QC-LDPC code in [4] also using a 50-iter-Flooding-SP decoder.

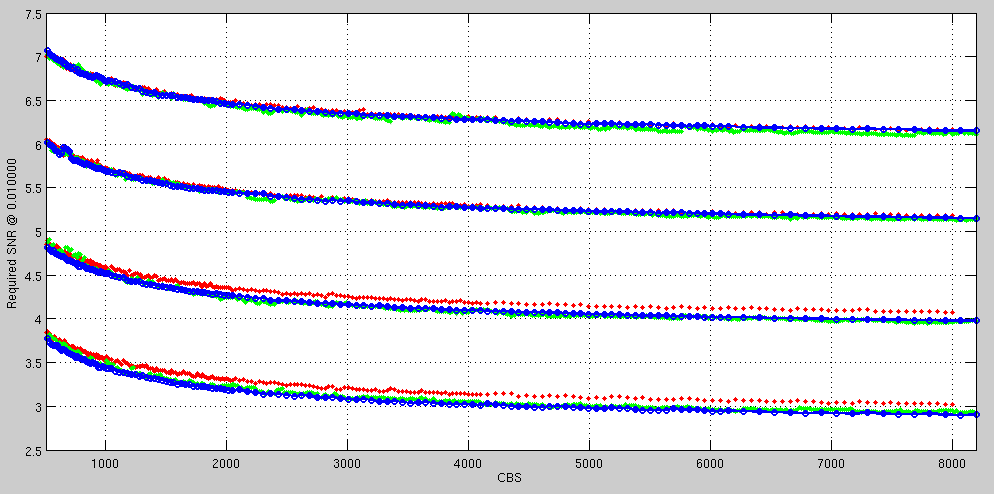


Figure 1: Required SNR at BLER=1e-2 for various CBS at CR=0.89, 0.83, 0.75 and 0.67

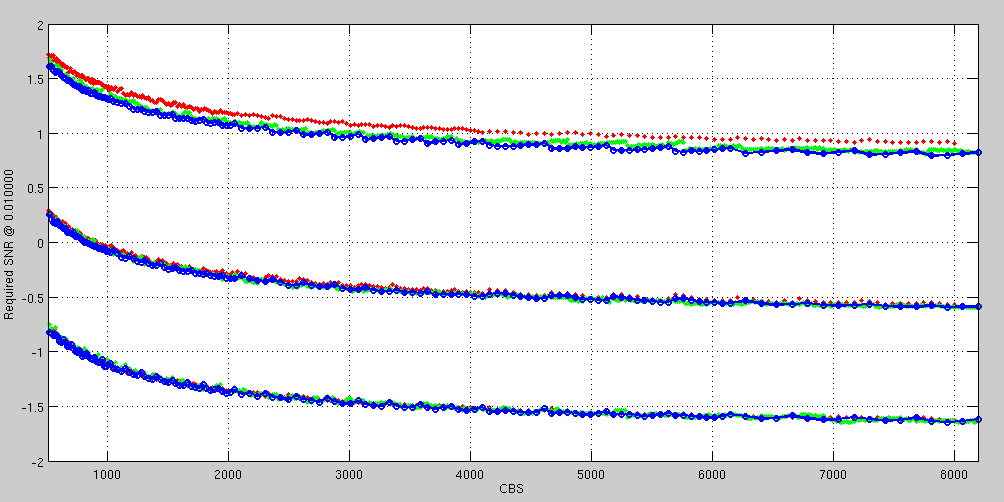


Figure 2: Required SNR at BLER=1e-2 for various CBS at CR=0.5, 0.4 and 0.33

## Required SNR at BLER=1e-4 Performance Comparisons

In the following figures, we try to compare the required SNR at BLER=1e-4 among different proposals of a QC-LDPC code. As can be seen in the figures below, the proposed compact QC-LDPC code can achieve competitive performance at BLER=1e-4.

The blue line is for the proposed QC-LDPC code A in [2] by Mediatek using a 50-iter-Flooding-SP decoder.

The red line is for the proposed QC-LDPC code in [3] also using a 50-iter-Flooding-SP decoder.

The green line is for the proposed QC-LDPC code in [4] also using a 50-iter-Flooding-SP decoder.

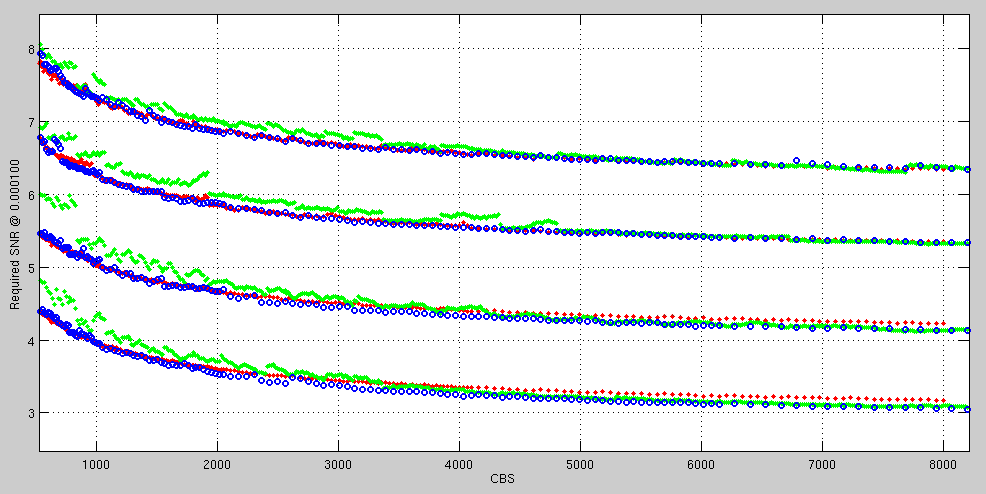


Figure 3: Required SNR at BLER=1e-4 for various CBS at CR=0.89, 0.83, 0.75 and 0.67

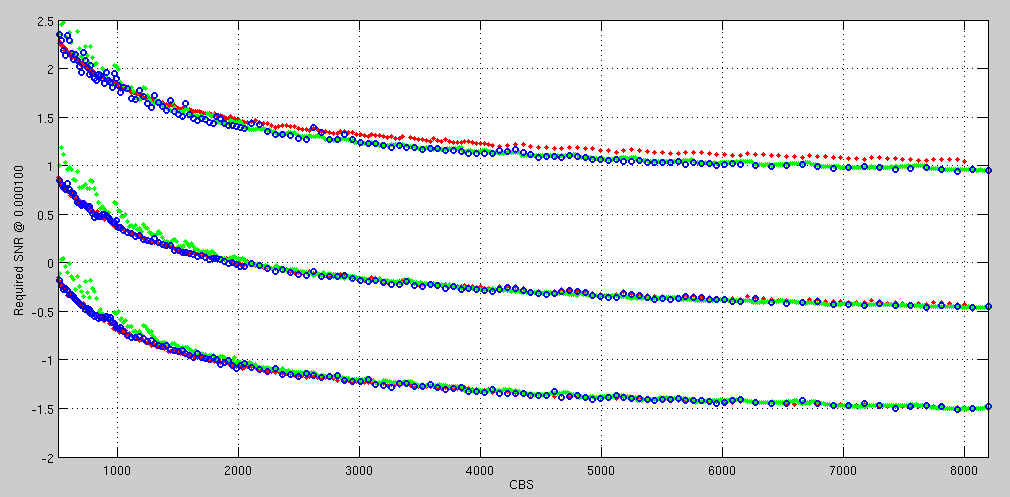


Figure 4: Required SNR at BLER=1e-4 for various CBS at CR=0.5, 0.4 and 0.33

**Observation 1:** The QC-LDPC code A proposed in [2] by Mediatek has competitive and in most cases best in class requisite SNR for BLER performance targets of 1e-2 and 1e-4.

## BLER vs. SNR Performance Comparisons

In the following figures, we plot the BLER vs. SNR curves among different proposals of a QC-LDPC code for some CBS/ CR combinations.

The CBS setting is 7808, 7168, 4160, 2624, 1088, and 528. Some of them are weak point pointed by other companies in R1-88 meeting and some are selected because of larger zero-padding size.

The CR setting is 0.89, 0.83, 0.75, 0.67, 0.5, 0.4 and 0.33.

The blue line is for the proposed QC-LDPC code A in [2] by Mediatek using a 50-iter-Flooding-SP decoder.

The red line is for the proposed QC-LDPC code in [3] also using a 50-iter-Flooding-SP decoder.

The green line is for the proposed QC-LDPC code in [4] also using a 50-iter-Flooding-SP decoder.

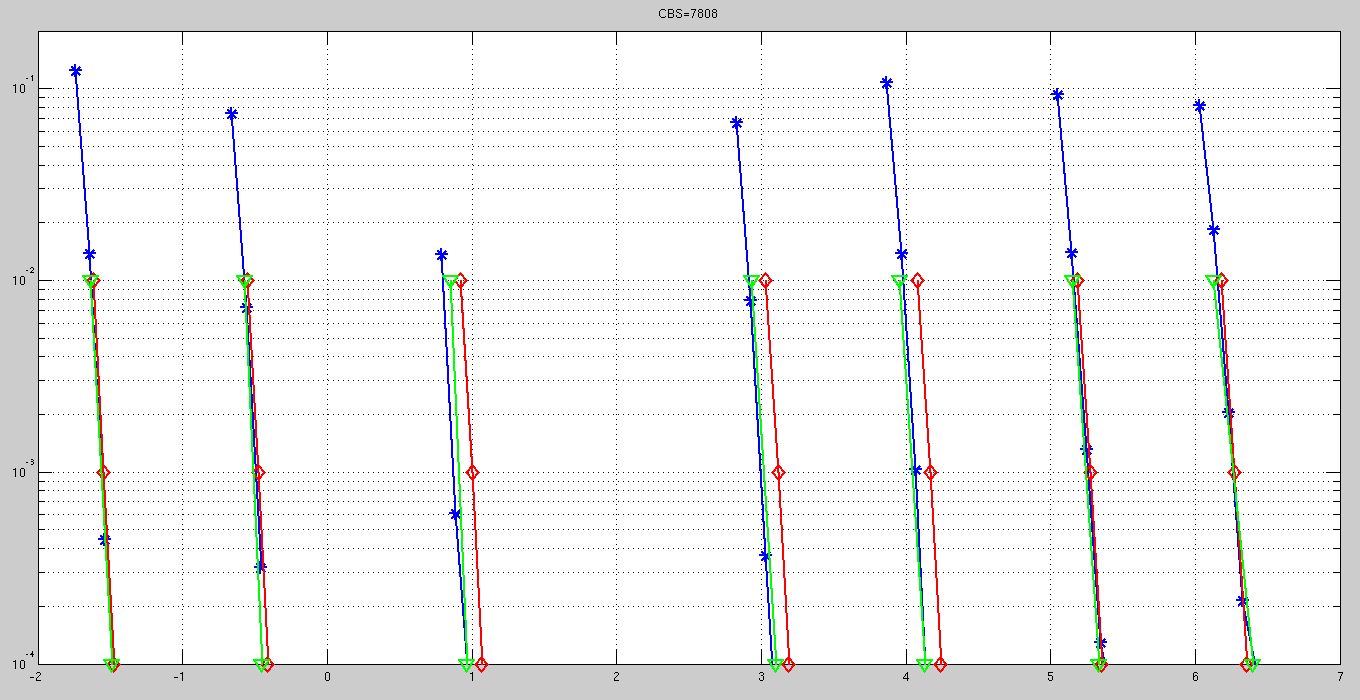


Figure 5: BLER vs. SNR for CBS=7808 at CR of 0.89, 0.83, 0.75, 0.67, 0.5, 0.4 and 0.33

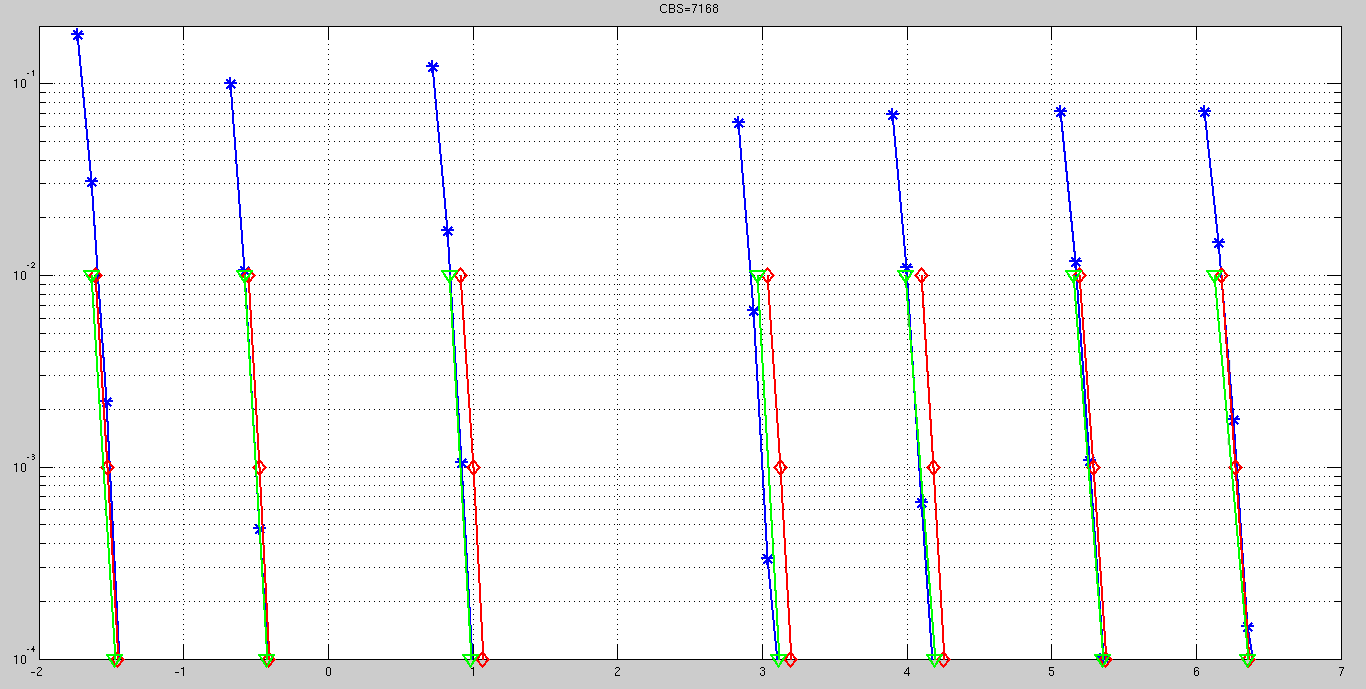


Figure 6: BLER vs. SNR for CBS=7168 at CR of 0.89, 0.83, 0.75, 0.67, 0.5, 0.4 and 0.33

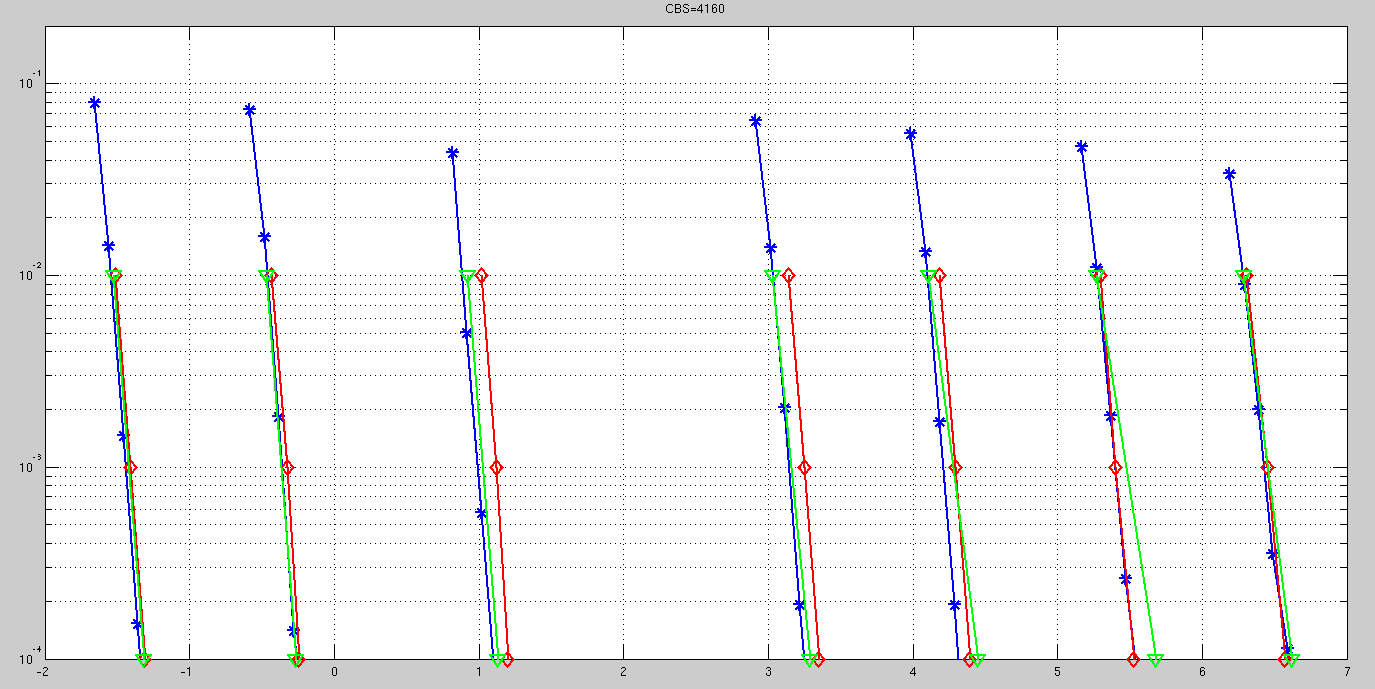


Figure 7: BLER vs. SNR for CBS=4160 at CR of 0.89, 0.83, 0.75, 0.67, 0.5, 0.4 and 0.33

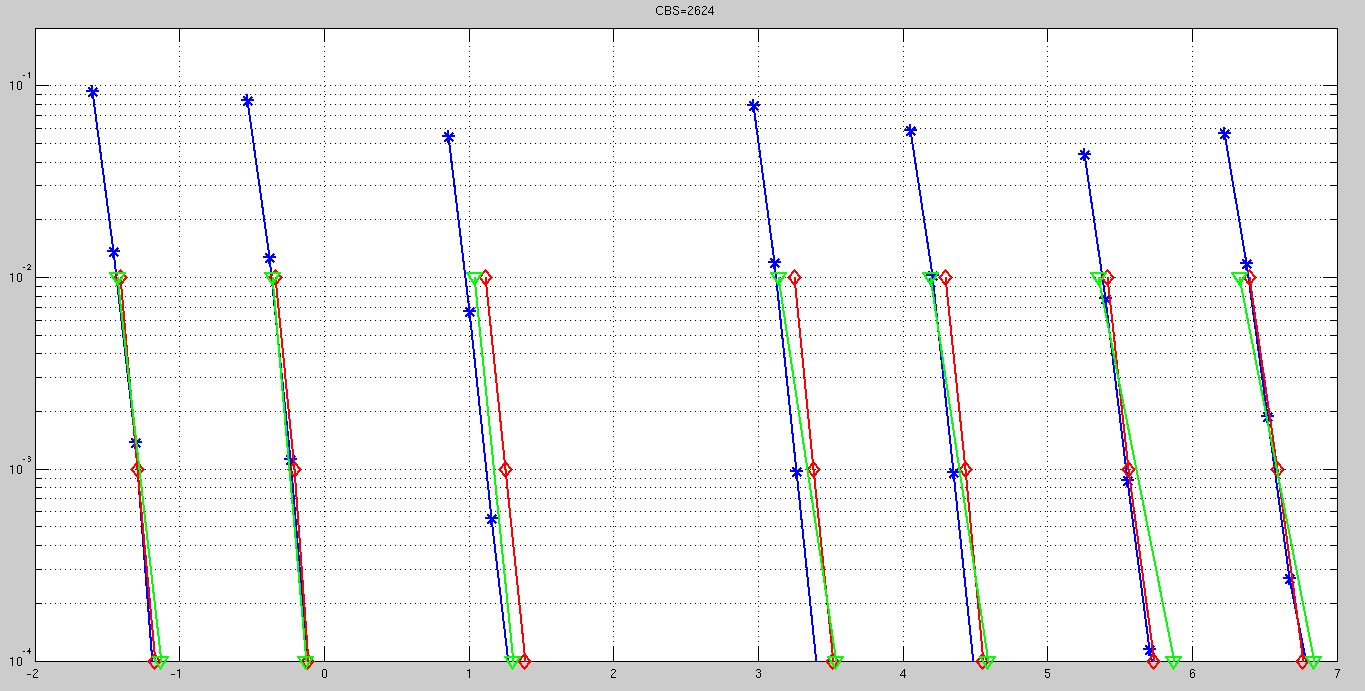


Figure 8: BLER vs. SNR for CBS=2624 at CR of 0.89, 0.83, 0.75, 0.67, 0.5, 0.4 and 0.33

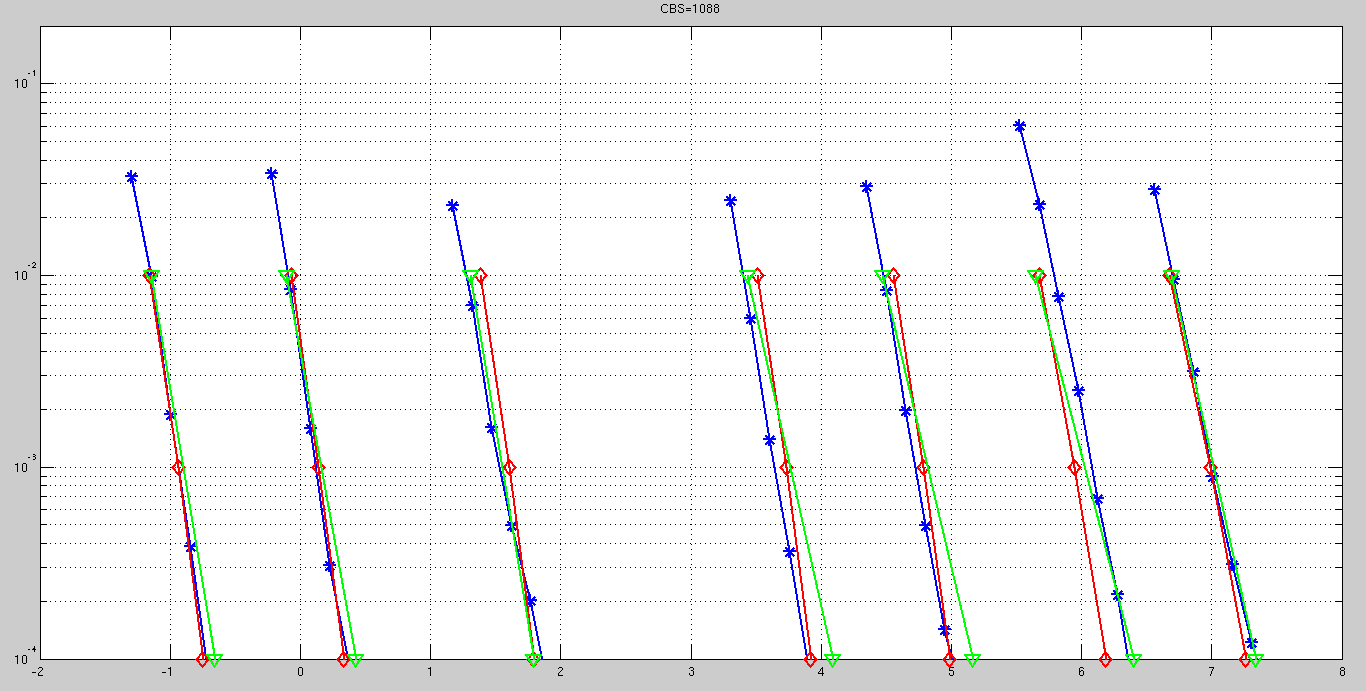


Figure 9: BLER vs. SNR for CBS=1088 at CR of 0.89, 0.83, 0.75, 0.67, 0.5, 0.4 and 0.33

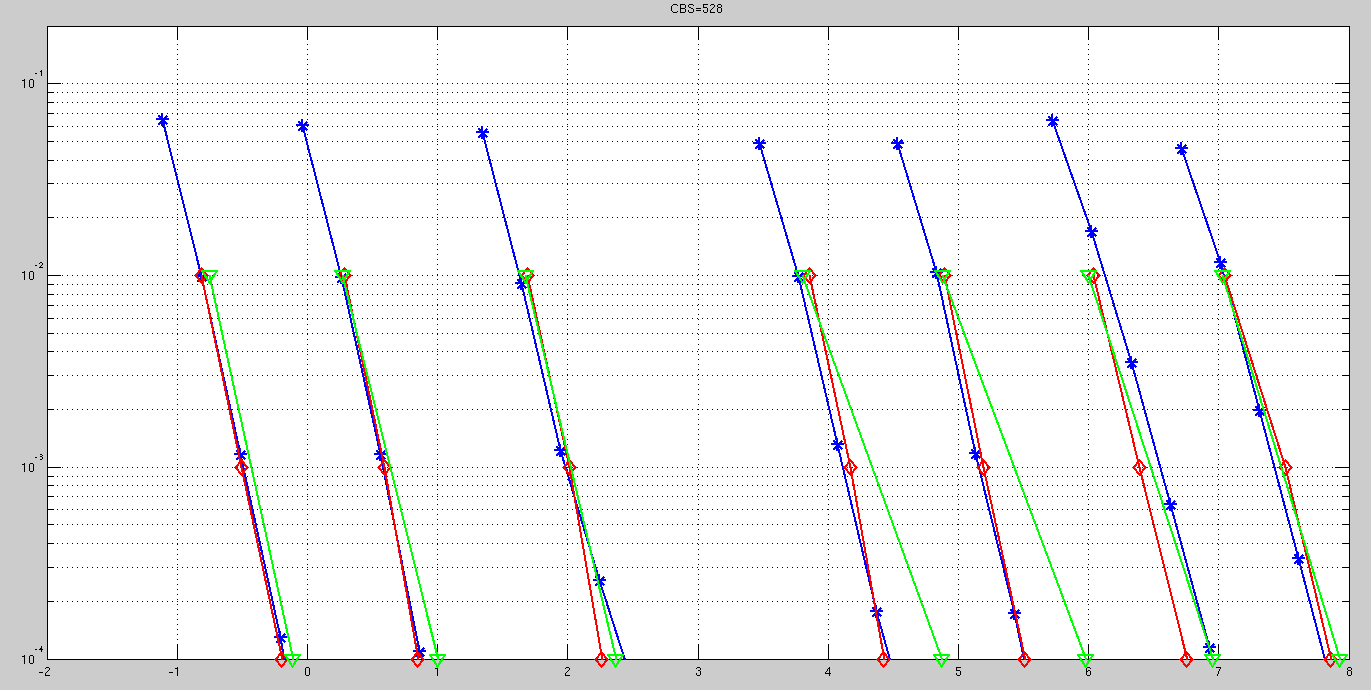


Figure 10: BLER vs. SNR for CBS=528 at CR of 0.89, 0.83, 0.75, 0.67, 0.5, 0.4 and 0.33

**Observation 2:** For the presented simulation set the compact QC-LDPC code proposed by Mediatek has competitive and in most cases best in class BLER performance with no error floor observed above 1e-4.

## Performance Statistic

There are too many simulation settings. In order to better compare the performance among different companies, we try to compare the required SNR difference at 1e-2 and 1e-4 and show some statistics on the gain among different CBS. The selected CRs are 0.33, 0.5, 0.67 and 0.89. We will focus on the CBS larger than 528. This is because this statistic better reflects the user experience and CBSs larger than 528 are more frequently used for eMBB data channel.

In Figure 11 to Figure 14, it is the comparisons between proposed QC-LDPC code A in [2] and that of [3].

The x-axis is the performance gain or loss. The y-axis is the number of counts at the depicted gain or loss. The green line is the loss-gain count at BLER=1e-2 and the red line is the loss-gain count at BLER=1e-4.

As you can see, the QC-LDPC proposed by Mediatek has better aggregate performance.

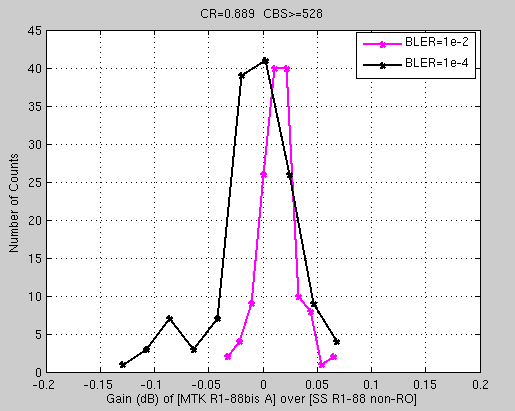


Figure 11

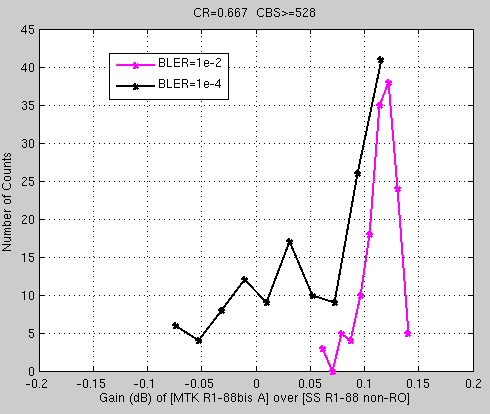


Figure 12

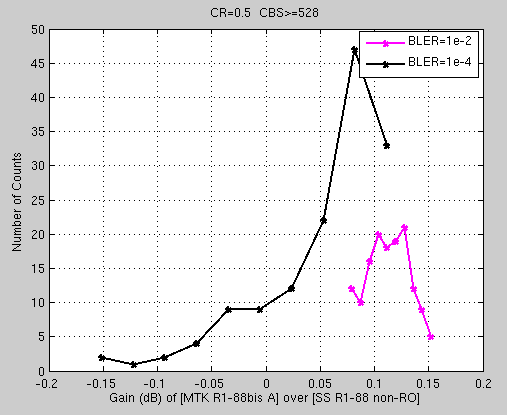


Figure 13

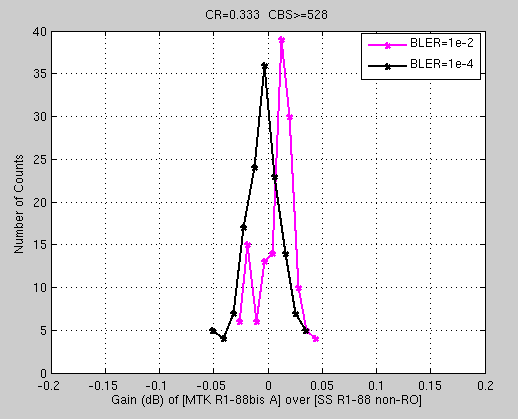


Figure 14

Figure 15 to Figure 18, shows the comparisons between proposed QC-LDPC code A in [2] and that of [4].

The x-axis is the performance gain or loss. The y-axis is the number of counts at the depicted gain or loss. The green line is the loss-gain count at BLER=1e-2 and the red line is the loss-gain count at BLER=1e-4.

As you can see, the QC-LDPC proposed by Mediatek has better aggregate performance.

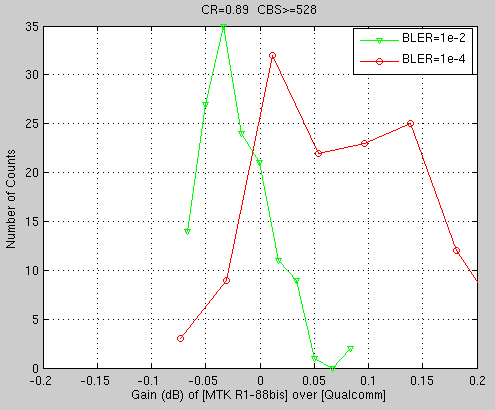


Figure 15

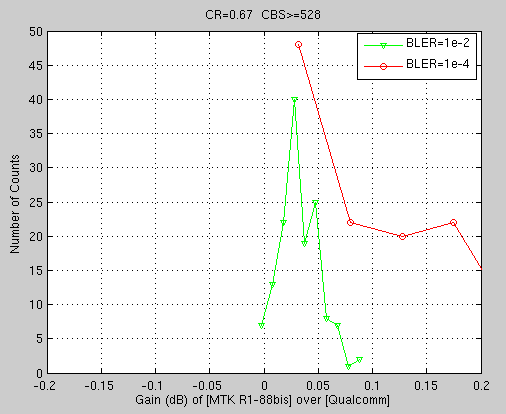


Figure 16

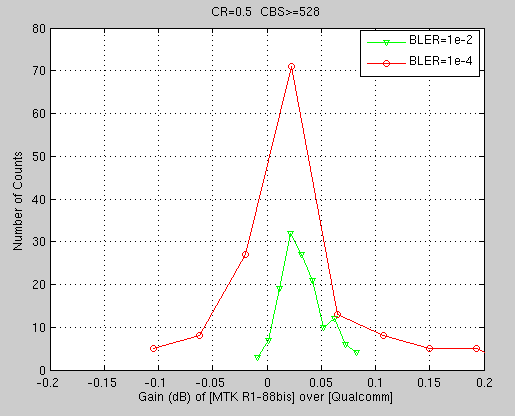


Figure 17

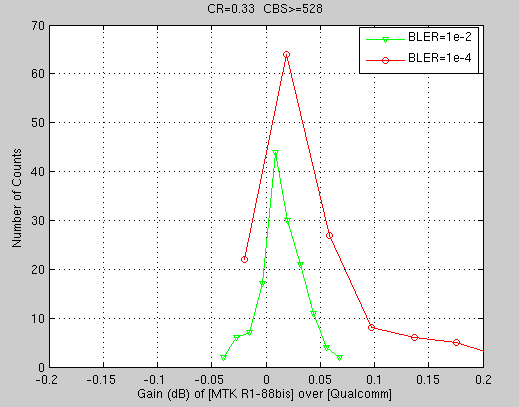


Figure 18

**Observation 3:** From a gain or loss statistical count analysis, we can easily find that the compact QC-LDPC code proposed by Mediatek has better aggregate performance than the QC-LDPC codes proposed in [3] and [4]

# Performance Comparisons with Proposed QC-LDPC Code B

In the following comparison, we will use early termination when the whole code word is correct by genie information and check the correctness of message bits for error count. The error count definition used is mostly close with that based on the definition used on LTE which early terminates the decoding when message bits are correct.

## Required SNR at BLER=1e-2 Performance Comparisons

In the following figures, we try to compare the required SNR at BLER=1e-2 among different proposals of a QC-LDPC code. As can be seen in the figures below, the proposed compact QC-LDPC code can achieve competitive performance at BLER=1e-2.

The blue line is for the proposed QC-LDPC code B in [2] by Mediatek using a 50-iter-Flooding-SP decoder.

The red line is for the proposed QC-LDPC code in [3] also using a 50-iter-Flooding-SP decoder.

The green line is for the proposed QC-LDPC code in [4] also using a 50-iter-Flooding-SP decoder.

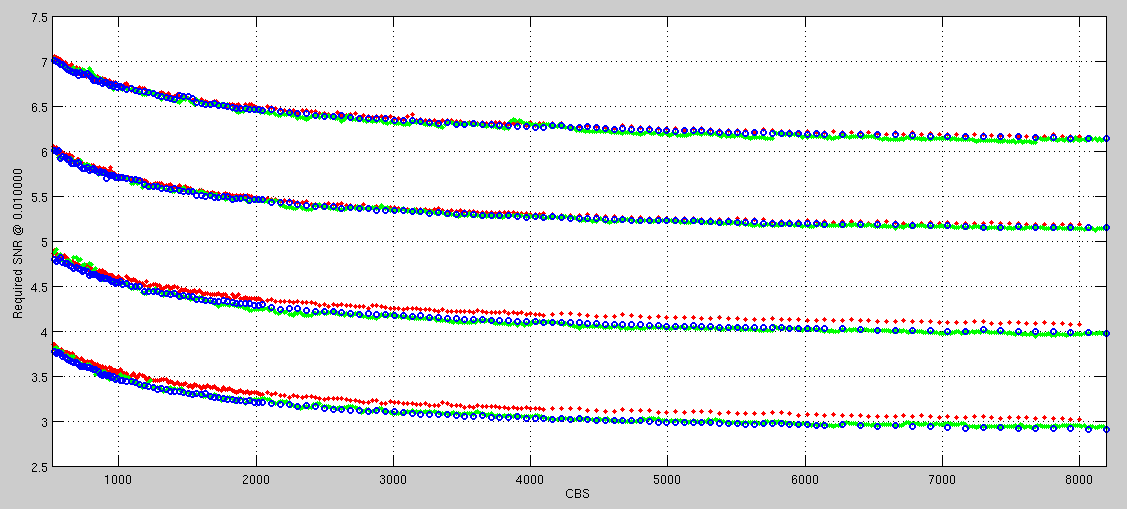


Figure 19: Required SNR at BLER=1e-2 for various CBS at CR=0.89, 0.83, 0.75 and 0.67

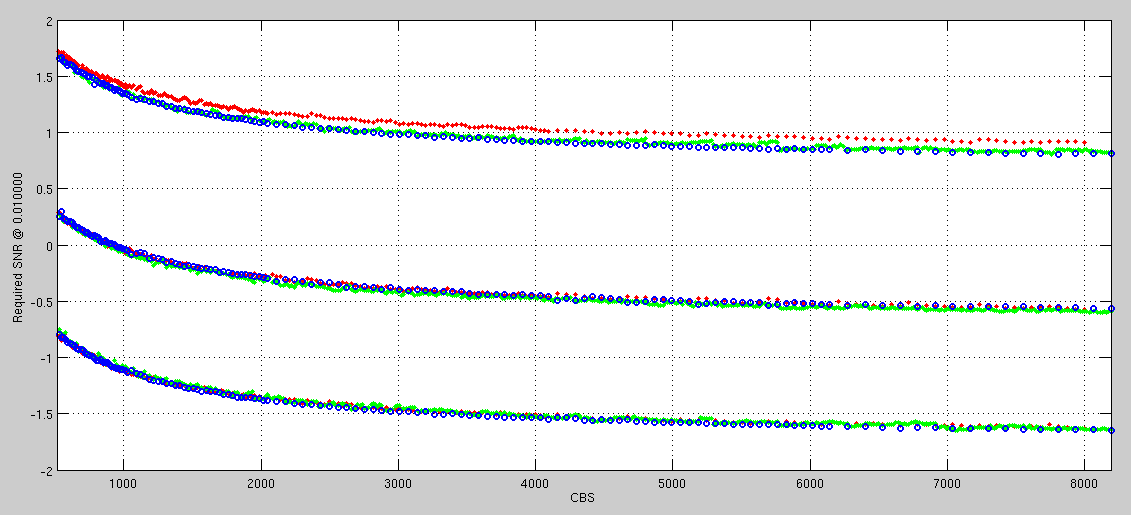


Figure 20: Required SNR at BLER=1e-2 for various CBS at CR=0.5, 0.4 and 0.33

## Required SNR at BLER=1e-4 Performance Comparisons

In the following figures, we try to compare the required SNR at BLER=1e-4 among different proposals of a QC-LDPC code. As can be seen in the figures below, the proposed compact QC-LDPC code can achieve competitive performance at BLER=1e-4.

The blue line is for the proposed QC-LDPC code B in [2] by Mediatek using a 50-iter-Flooding-SP decoder.

The red line is for the proposed QC-LDPC code in [3] also using a 50-iter-Flooding-SP decoder.

The green line is for the proposed QC-LDPC code in [4] also using a 50-iter-Flooding-SP decoder.

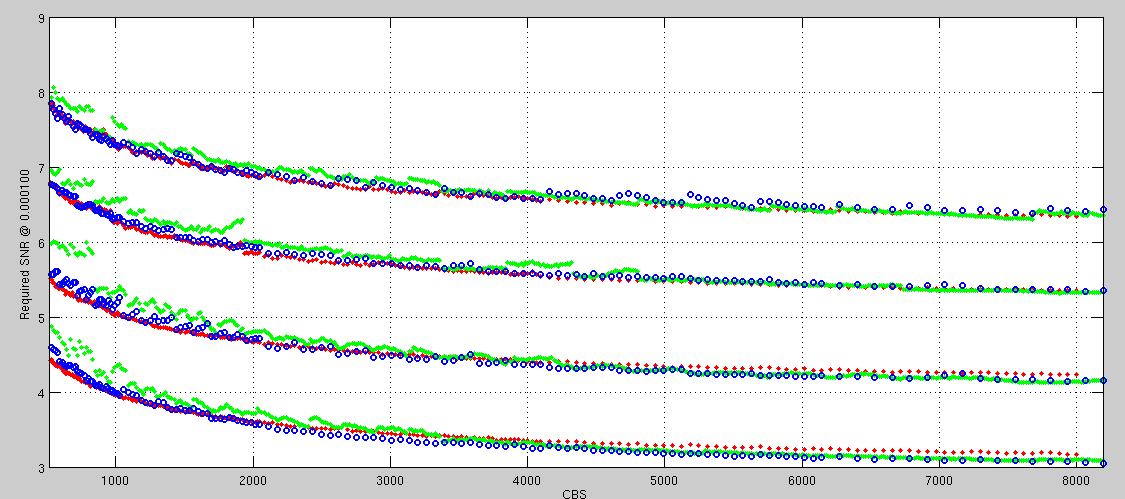


Figure 21: Required SNR at BLER=1e-4 for various CBS at CR=0.89, 0.83, 0.75 and 0.67

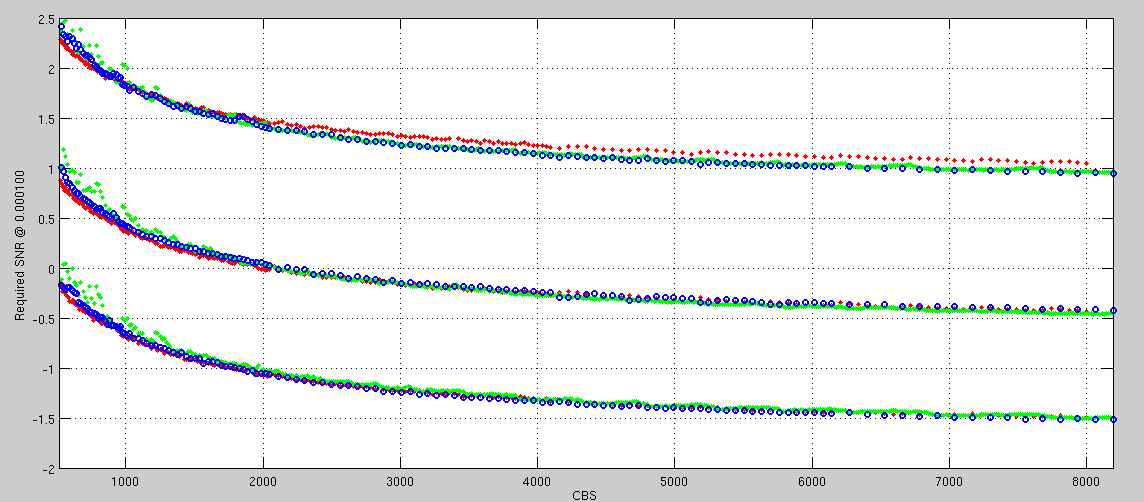


Figure 22: Required SNR at BLER=1e-4 for various CBS at CR=0.5, 0.4 and 0.33

**Observation 4:** The QC-LDPC code B proposed in [2] by Mediatek has competitive and in most cases best in class requisite SNR for BLER performance targets of 1e-2 and 1e-4.

## BLER vs. SNR Performance Comparisons

In the following figures, we plot the BLER vs. SNR curves among different proposals of a QC-LDPC code for some CBS/ CR combinations.

The CBS setting is 7808, 7168, 4160, 2624, 1088, and 528. Some of them are weak point pointed by other companies in R1-88 meeting and some are selected because of larger zero-padding size.

The CR setting is 0.89, 0.83, 0.75, 0.67, 0.5, 0.4 and 0.33.

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The red line is for the proposed QC-LDPC code in [3] also using a 50-iter-Flooding-SP decoder.

The green line is for the proposed QC-LDPC code in [4] also using a 50-iter-Flooding-SP decoder.

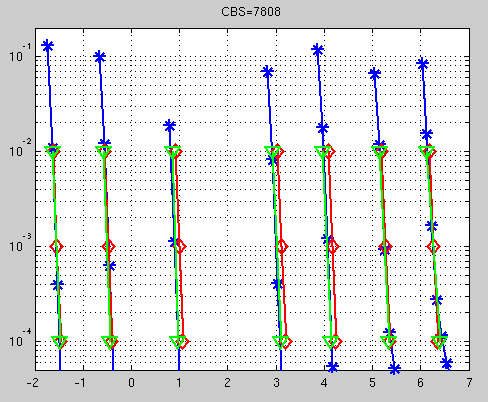


Figure 23: BLER vs. SNR for CBS=7808 at CR of 0.89, 0.83, 0.75, 0.67, 0.5, 0.4 and 0.33

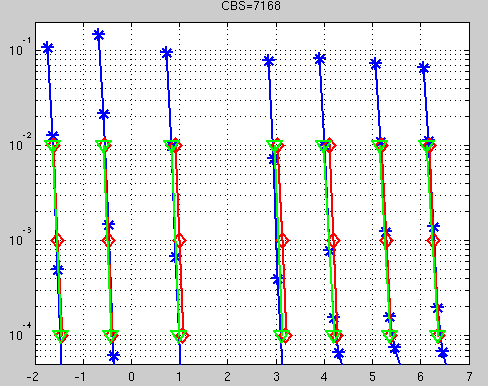


Figure 24: BLER vs. SNR for CBS=7168 at CR of 0.89, 0.83, 0.75, 0.67, 0.5, 0.4 and 0.33

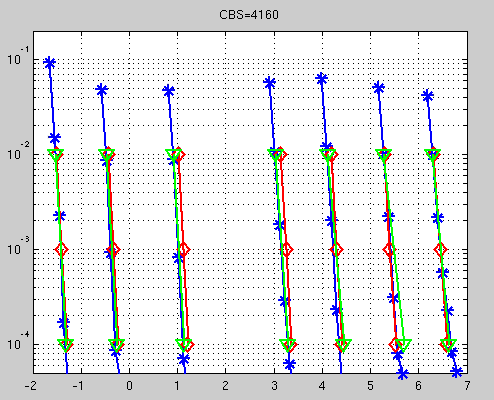


Figure 25: BLER vs. SNR for CBS=4160 at CR of 0.89, 0.83, 0.75, 0.67, 0.5, 0.4 and 0.33

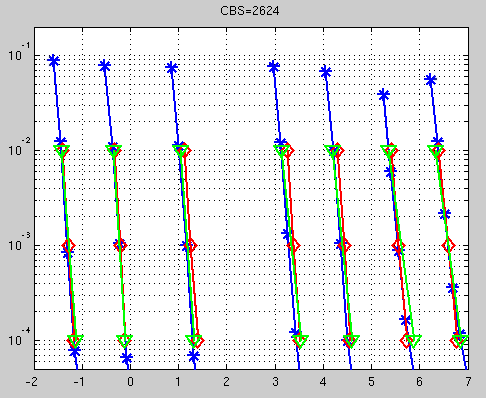


Figure 26: BLER vs. SNR for CBS=2624 at CR of 0.89, 0.83, 0.75, 0.67, 0.5, 0.4 and 0.33

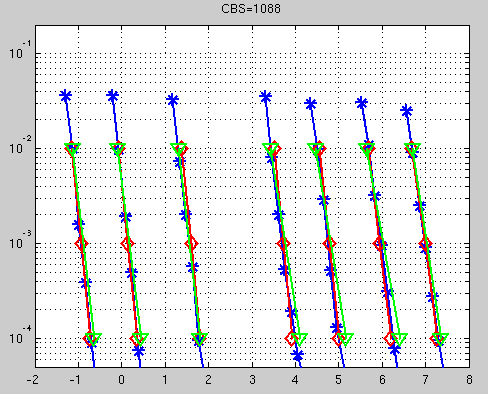


Figure 27: BLER vs. SNR for CBS=1088 at CR of 0.89, 0.83, 0.75, 0.67, 0.5, 0.4 and 0.33

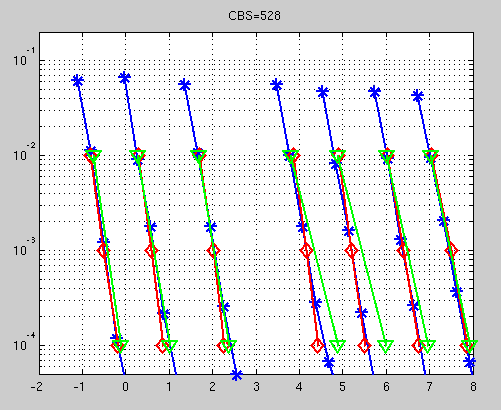


Figure 28: BLER vs. SNR for CBS=528 at CR of 0.89, 0.83, 0.75, 0.67, 0.5, 0.4 and 0.33

**Observation 5:** For the presented simulation set the compact QC-LDPC code B proposed by Mediatek has competitive and in most cases best in class BLER performance with no error floor observed above 1e-4.

## Performance Statistic

There are too many simulation settings. In order to better compare the performance among different companies, we try to compare the required SNR difference at 1e-2 and 1e-4 and show some statistics on the gain among different CBS. The selected CRs are 0.33, 0.5, 0.67 and 0.89. We will focus on the CBS larger than 528. This is because this statistic better reflects the user experience and CBSs larger than 528 are more frequently used for eMBB data channel.

In Figure 29 to Figure 32, it is the comparisons between proposed QC-LDPC code B in [2] and that of [3].

The x-axis is the performance gain or loss. The y-axis is the number of counts at the depicted gain or loss. The green line is the loss-gain count at BLER=1e-2 and the red line is the loss-gain count at BLER=1e-4.

As you can see, the QC-LDPC proposed by Mediatek has better aggregate performance.

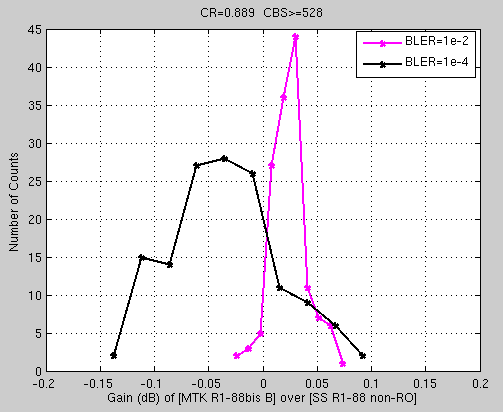


Figure 29

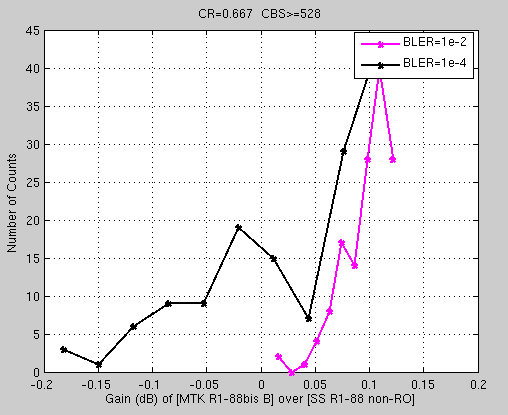


Figure 30

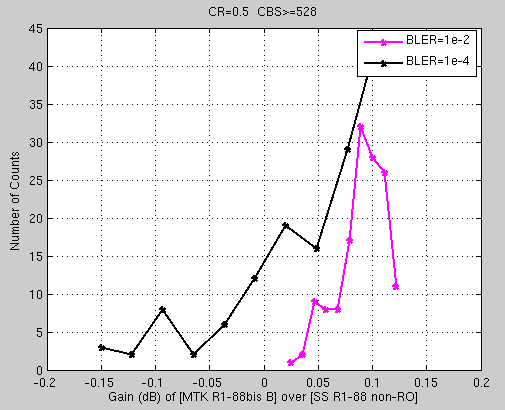


Figure 31

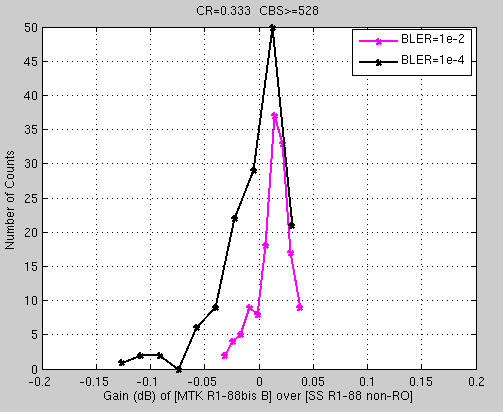


Figure 32

Figure 33 to Figure 36, shows the comparisons between proposed QC-LDPC code B in [2] and that of [4].

The x-axis is the performance gain or loss. The y-axis is the number of counts at the depicted gain or loss. The green line is the loss-gain count at BLER=1e-2 and the red line is the loss-gain count at BLER=1e-4.

As you can see, the QC-LDPC proposed by Mediatek has better aggregate performance.

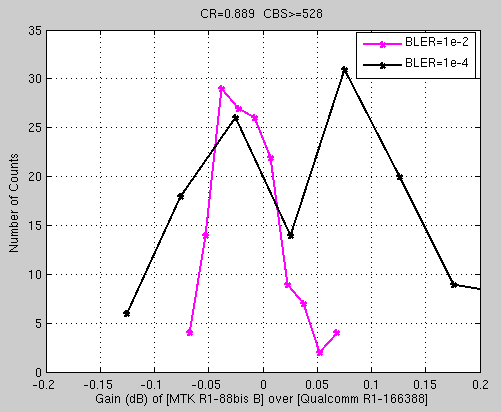


Figure 33

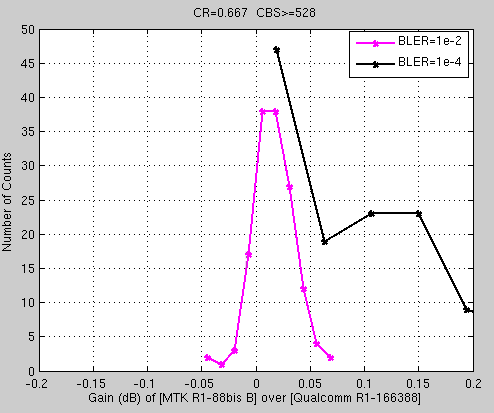


Figure 34

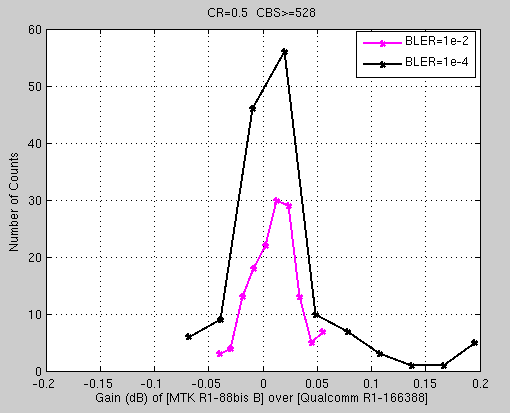


Figure 35

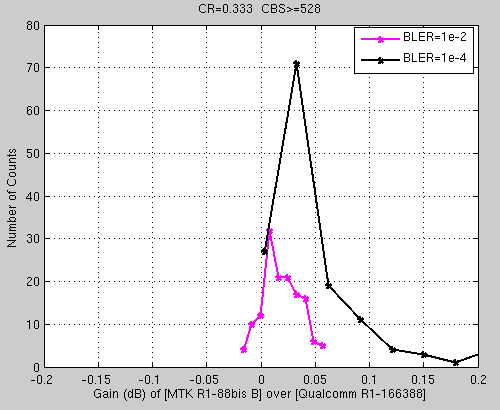


Figure 36

**Observation 6:** From a gain or loss statistical count analysis, we can easily find that the QC-LDPC code B proposed in [2] have better aggregate performance than the QC-LDPC codes proposed in [3] and [4]

# Conclusion

The following summarizes the observations and proposals in this contribution.

**Observation 1:** The QC-LDPC code A proposed in [2] by Mediatek has competitive and in most cases best in class requisite SNR for BLER performance targets of 1e-2 and 1e-4.

**Observation 2:** For the presented simulation set the compact qRO QC-LDPC code A proposed by Mediatek has competitive and in most cases best in class BLER performance with no error floor observed above 1e-4.

**Observation 3:** From a gain or loss statistical count analysis, we can easily find that the QC-LDPC code A proposed in [2] have better aggregate performance than the QC-LDPC codes proposed in [3] and [4]

**Observation 4:** The QC-LDPC code B proposed in [2] by Mediatek has competitive and in most cases best in class requisite SNR for BLER performance targets of 1e-2 and 1e-4.

**Observation 5:** For the presented simulation set the compact qRO QC-LDPC code B proposed by Mediatek has competitive and in most cases best in class BLER performance with no error floor observed above 1e-4.

**Observation 6:** From a gain or loss statistical count analysis, we can easily find that the QC-LDPC code B proposed in [2] have better aggregate performance than the QC-LDPC codes proposed in [3] and [4]

# References

1. R1-1700866, Evaluation of LDPC codes for eMBB data channels
2. R1-1706175, A multi-codebook embedded compact QC-LDPC design, Mediatek
3. R1-1703001, Performance evaluation of LDPC Code, Samsung
4. R1-166388, LDPC rate compatible design, Qualcomm