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Agenda Item: **7.4.5**

Source: **Nortel**

Title: **MCS Selection for LTE**

Document for: **Discussion**

1 Introduction

For E-UTRA downlink transmission, a set of modulation and coding scheme (MCS) needs to be defined. Ideally, we would like the SINR delta between consecutive MC set evenly distributed, with an interval of about 1~1.5dB.

In LTE, there are 188 Turbo code block sizes (CBS) under consideration, from 40 to 6144 bits. It is well known that the performance of each MC set is CBS dependent. Therefore, how well a set of MC can maintain their relative relation in terms of performance SINR for different CBS is also an interesting question.

For the two kinds of channels under consideration in LTE, namely distributed and localized channel, distributed channel shows a much different characteristic from AWGN channel. For this reason, we can expect that the MCS sets for a distributed channel can be somewhat different from AWGN, and therefore, localized channel. This raises an interesting question, i.e. how different is the MCS performance between different MIMO modes, i.e. SFBC and SM, in a distributed channel.

And finally, we would like to understand what the impact of UE speed is and how channel estimation affects MCS selection.

This contribution is to present our investigation results for all these questions.

2 Link-Level Simulation Set-Up

MCS simulation for distributed fading is much more demanding than AWGN. Since the results with channel estimation is estimation algorithm dependent, we need to simulation perfectly known channel as well, not only to see whether performance degradation is reasonable, but also to have a reference to see whether the obtained relative relation is still aligned. In addition, an MCS needs to be evaluated in both SFBC and SM. To make simulation results complete, different UE speed needs to be considered, too. This increases the number of simulation cases by eight times for each MCS — if we limit the number of UE speed that needs to be investigated to two.

Since this simulation is for estimated channel, a channel estimation algorithm is needed. The problem is that there is no ‘standard’ channel algorithm available, so we have to come up with our own. It is fully understood that different channel algorithm will affect performance differently; but it is also understood that a reasonably well designed estimation algorithm shall not change the conclusions we have drawn from this work. To achieve this objective we used a high performance estimation algorithm, and simulated perfectly known channel for cross check and as a reference.

It is well known that the optimum channel estimation algorithm is 2D Wiener filtering[1]. However, this algorithm is too complicated and hence is unlikely to be used in real design. To simplify the algorithm, we came up with an adaptive channel interpolation algorithm, together with the diamond shape pilot pattern. This work also influenced the current LTE standards in DL reference symbol design.

The algorithm can be briefly described as follows:

1. Detect in which direction (i.e. time or frequency) the channels changes slower;
2. Do 1-D Winner filtering in that direction;
3. Do 1-D interpolation in that direction;
4. Do 1-D interpolation in the other direction.

The pilots used in this evaluation include three sub-frames, i.e. current, previous, and next. Both adaptive filtering and interpolation are used to exploit channel correlation and hence improve estimation quality. The object is to use a 1-D algorithm to achieve close to 2-D performance. Interpolation uses 3rd order Lagrange polynomial.

In this investigation, we assumed uniform puncturing for rate matching. This is the common practice in Turbo codes/interleaver evaluation. The purpose is to simplify the simulation work and separate this investigation from the specific rate-matching algorithm we are going to use. It is understood that no remarkable performance difference will be observed when a well-designed rate-matching algorithm is employed.

For channel interleaver, we followed Rel-7. The system bandwidth is 10MHz.

Since there are total 188 Turbo code block sizes, it is simply impossible to simulate them all. However, to capture a whole picture of MCS performance under different Turbo code block sizes, we select the sizes which are representative of all the sizes. The selected sizes are: 160, 640, and 6144, in total three sizes. The objective is to make the performances evenly distributed in terms of SNR, and hence the performances of other block sizes can be obtained through interpolation of the simulated results.

The intention for the modulation and coding set selection at this stage is to be as complete as possible; this means we need to simulate the performance for code rate as low as 1/8. Even though we may not implement code rate 1/8 for initial data transmission, this code rate could be a result of HARQ. Note that we do not simulate code rates 1/6 and 1/9, because they are about 3dB and 4.8dB shift of a code rate 1/3 curve. The code rates are obtain through even puncturing of the parity bits from a 1/3 mother code. For codes with code rate lower than 1/3, they are formed through a 1/3 code plus a partially punctured code. For example, a code rate 1/8 code is formed from a 1/3 code as follows: 1/3 + 1/3 + 1/2. Note that since there are so many code rates variation, it is impractical to simulate all the cases (e.g. 7/15). What we simulated here are based on 'commonly' used code rates, i.e. those code rates mostly seen from LTE contributions for system evaluations, with some additional code rates we believe that could be possible candidates for the trial. This would provide us with a base of enough granularities for MCS selection and interpolation.

The MCS sets used for simulation are listed in Table 1. There are total 29 MCS sets to be investigated. These MCS sets will be applied to each of the three Turbo block sizes.

Considering that there are two MIMO modes (i.e. SFBC and SM), we have total 174 cases to simulate. This is not all. To verify the performance under high mobility, we need to simulate different mobile speeds as well. Since the objective is MCS selection, we assume that SINR at the receiver is always known, so that the task is to see how each MCS performs under a certain SINR. Considering the simulation cases we already have, we limited our simulation to two mobile speeds: 3kmph and 120kmph, i.e. nomadic and high

[1] P. Hoeher, et al, "Two-Dimensional Pilot-Symbol-Aided Channel Estimation by Wiener Filtering", *IEEE ICASSP-97*, vol 3, pp. 1845-1848, 21-24 April 1997.

mobility. This selection also considers how channel estimation contributes to these two typical application scenarios.

The antenna configuration simulated in this contribution is [2Tx, 2Rx].

Table 1 MCS sets used in simulation

MCS	Modulation	Code rate	Efficiency
1	QPSK	1/8	0.25
2	QPSK	1/7	0.29
3	QPSK	1/5	0.40
4	QPSK	1/4	0.50
5	QPSK	1/3	0.67
6	QPSK	2/5	0.80
7	QPSK	3/7	0.86
8	QPSK	1/2	1.00
9	QPSK	3/5	1.20
10	QPSK	2/3	1.33
11	QPSK	3/4	1.50
12	QPSK	4/5	1.60
13	QPSK	5/6	1.67
14	16QAM	2/5	1.60
15	16QAM	3/7	1.71
16	16QAM	1/2	2.00
17	16QAM	3/5	2.40
18	16QAM	2/3	2.67
19	16QAM	3/4	3.00
20	16QAM	4/5	3.20
21	16QAM	5/6	3.33
22	64QAM	2/5	2.40
23	64QAM	3/7	2.57
24	64QAM	1/2	3.00
25	64QAM	3/5	3.60
26	64QAM	2/3	4.00
27	64QAM	3/4	4.50
28	64QAM	4/5	4.80
29	64QAM	5/6	5.00

3 Simulation results

In this section, simulation results are presented for

- Different MIMO modes (i.e. SFBC and SM);
- Different vehicle speed (3km/h and 120 km/h);
- Perfectly known channel and estimated channel;
- Different FEC code block sizes.

According to these results, two candidate MCS tables are recommended.

3.1 MCS with Fixed Block Sizes / SFBC / 3kmph

In this section, the performances of different MCS sets with fixed block sizes in SFBC mode are presented. The purpose of this exercise is to identify the MCS granularity, and to see whether different Turbo code blocks can share a common selected MCS sets so as to simplify the AMC process.

The simulated results are shown in Figure 1—Figure 6. It can be noticed that the trends of the performances for different MCS sets are the same for all the block sizes simulated. In addition, according to the simulation results, the MCS set as shown in Table 2 can be selected, which is applicable to all block sizes. The selection criterion is SNR vs. efficiency. The MCS requires higher operating point than an MCS of equal or higher efficiency will be eliminated. The corresponding effective information data rate (bits per QAM × code rate) vs. MCS indexes is shown in Figure 9. The selected MCS performance curves corresponding to Turbo code block size 640 are given in Figure 7 and Figure 8.

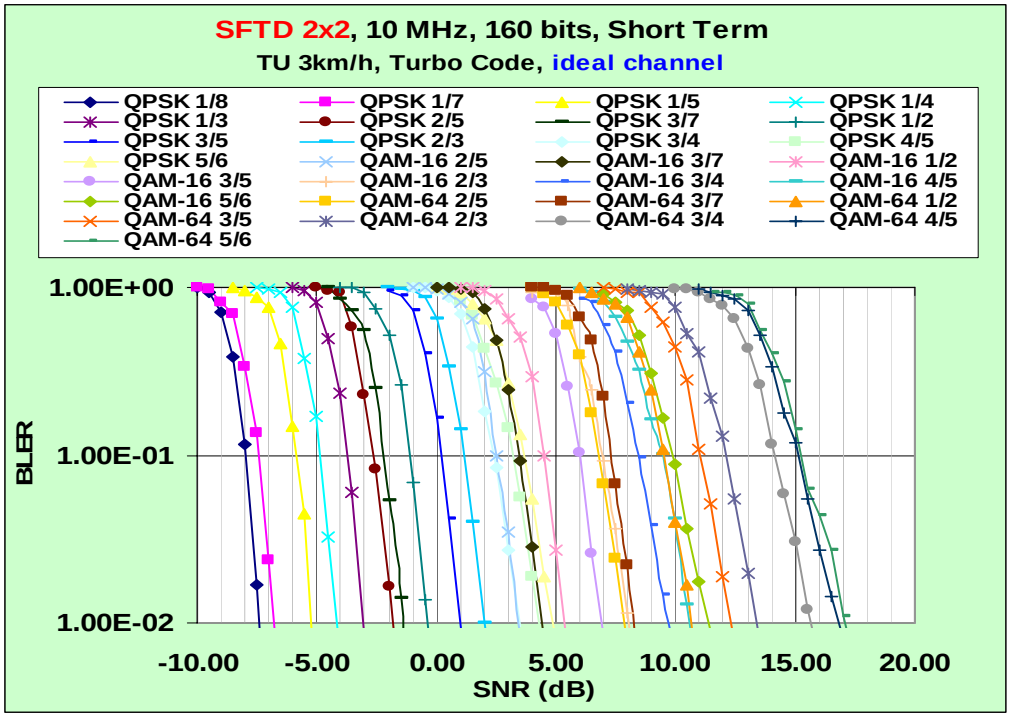

Figure 1 TU known channel, 3kmph, Turbo code block size 160 bits.

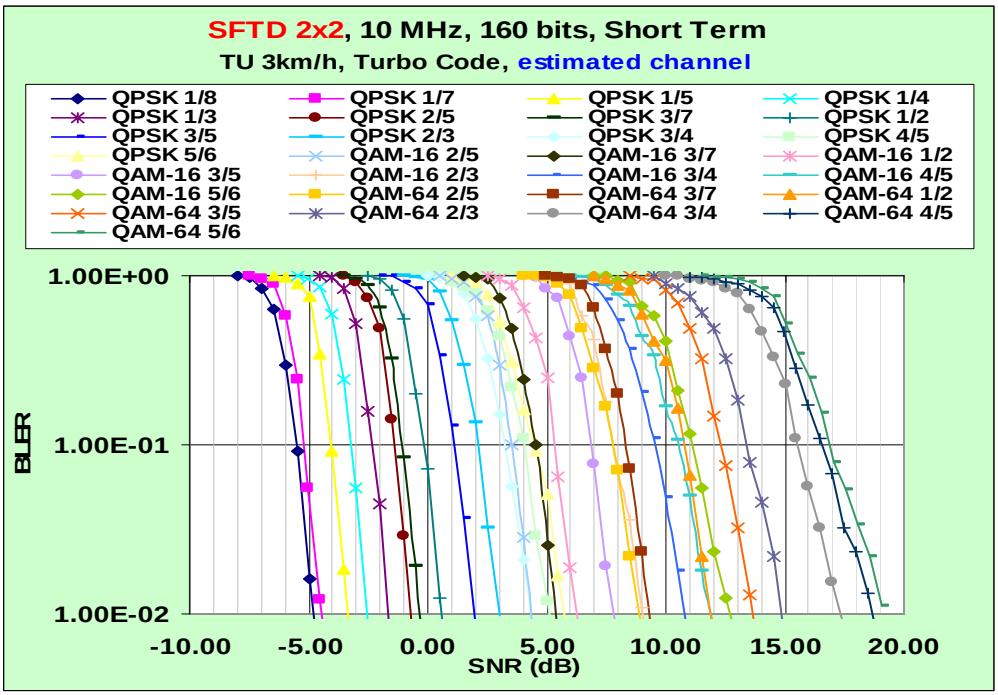

Figure 2 TI estimated channel, 3kmph, Turbo code block size 160 bits

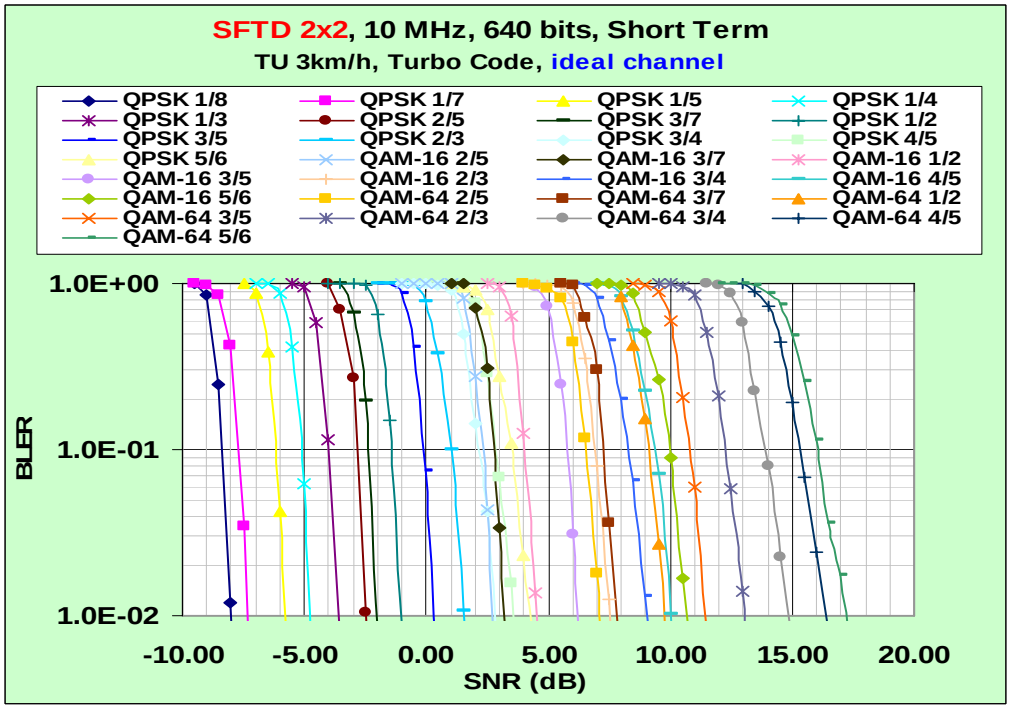

Figure 3 TU known channel, 3kmph, Turbo code block size 640 bits

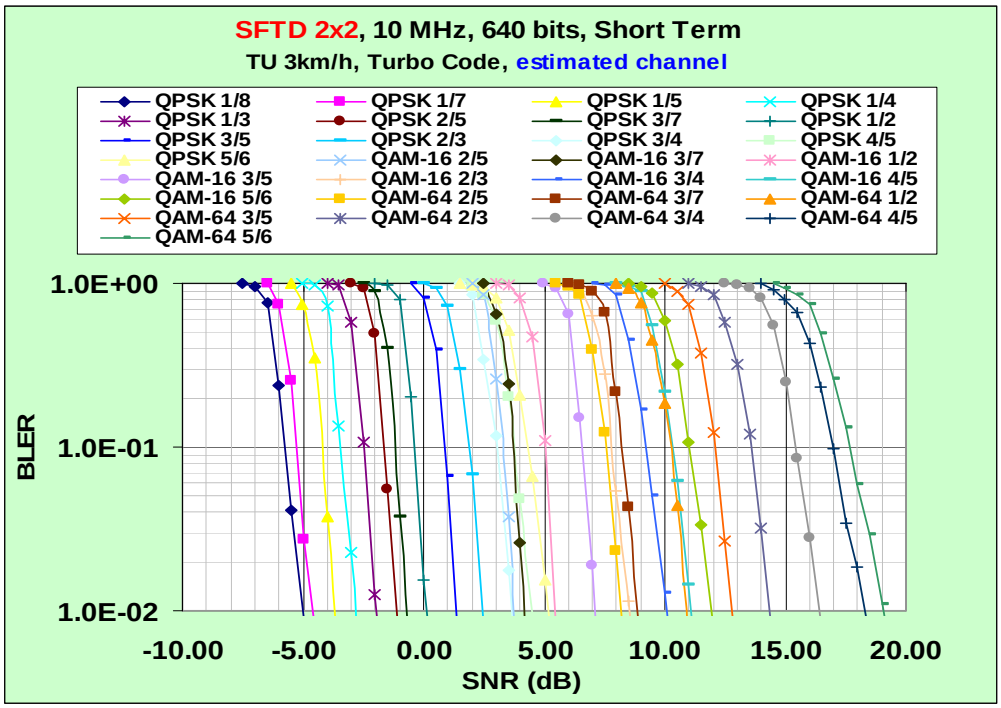

Figure 4 TU known channel, 3kmph, Turbo code block size 640 bits

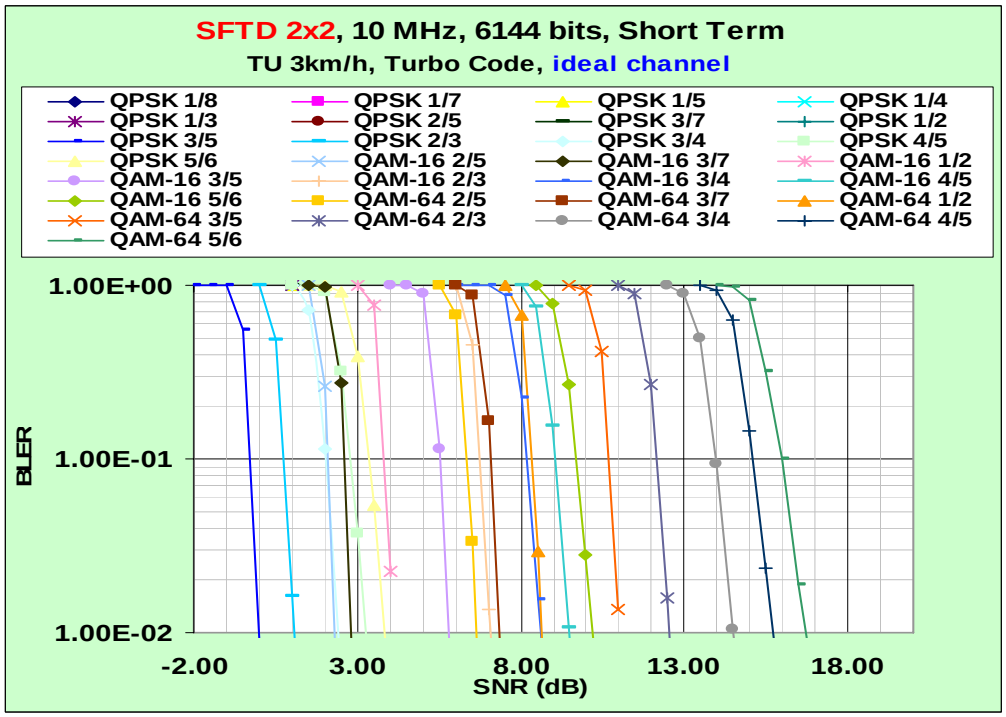

Figure 5 TU known channel, 3kmph, Turbo code block size 6144 bits

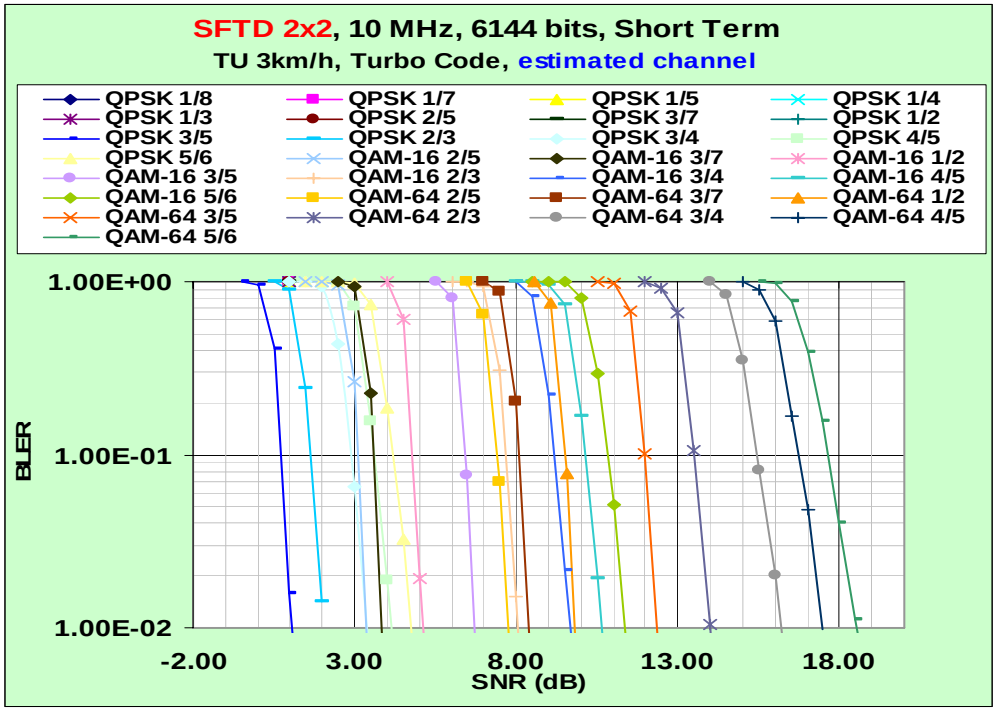

Figure 6 TU estimated channel, 3kmph, Turbo code block size 6144 bits

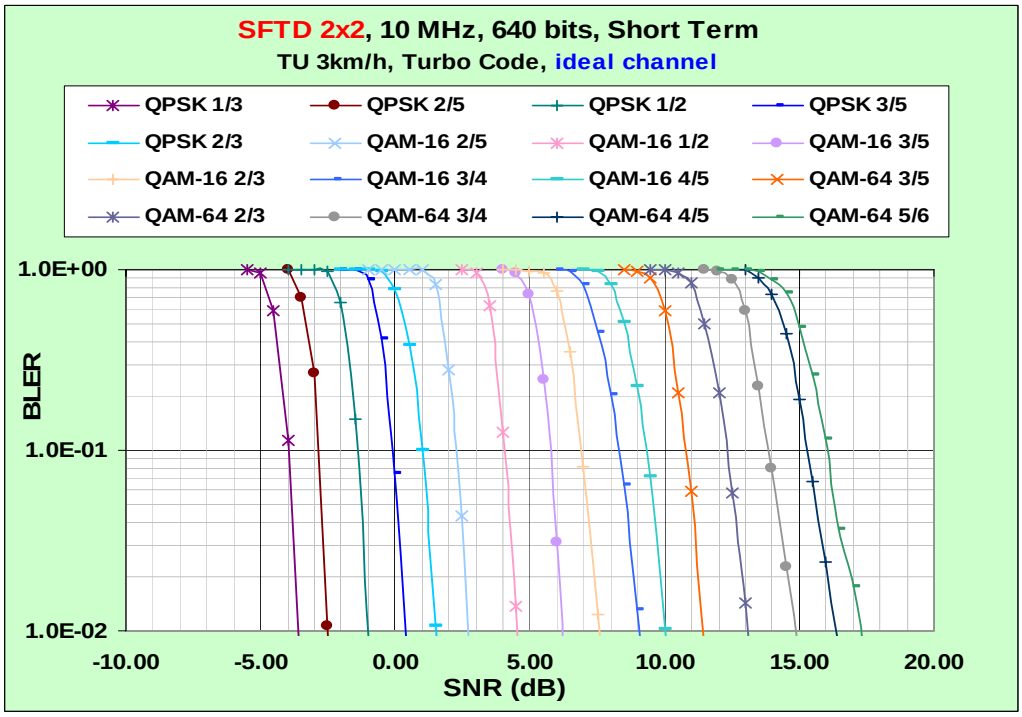

Figure 7 TU MCS set with 16 entries – SFBC 3kmph known channel

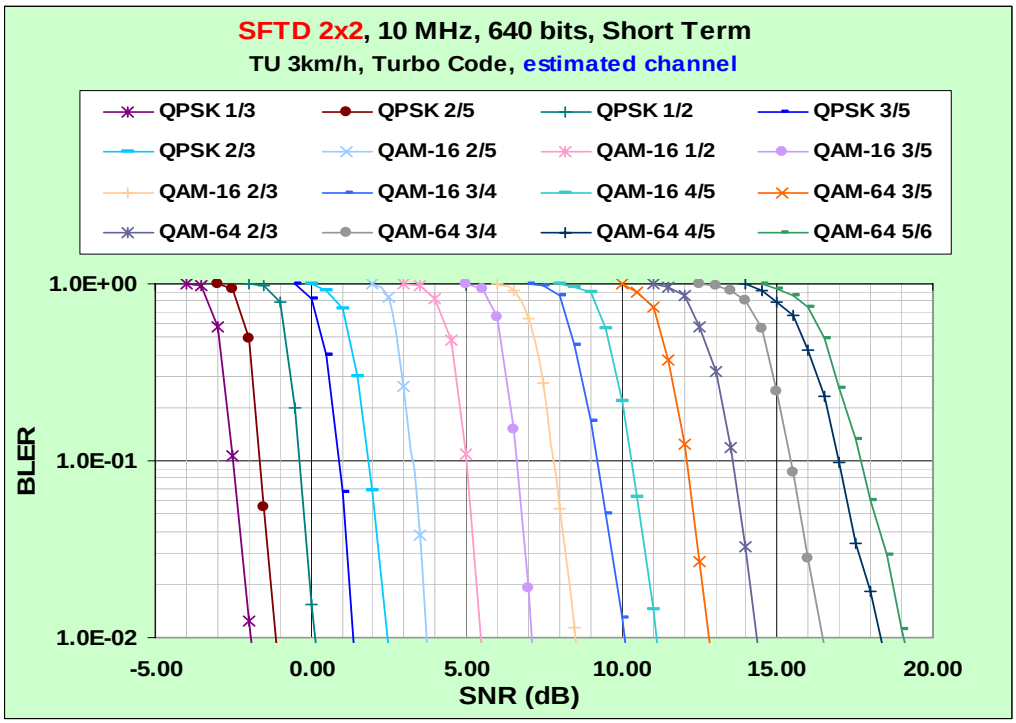

Figure 8 TU MCS set with 16 entries – SFBC 3kmph estimated channel

Table 2 MCS table based on SFBC simulation results

MCS	Modulation	Code rate	Efficiency
1	QPSK	1/3	0.67
2	QPSK	2/5	0.80
3	QPSK	1/2	1.00
4	QPSK	3/5	1.20
5	QPSK	2/3	1.33
6	16QAM	2/5	1.60
7	16QAM	1/2	2.00
8	16QAM	3/5	2.40
9	16QAM	2/3	2.67
10	16QAM	3/4	3.00
11	16QAM	4/5	3.20
12	64QAM	3/5	3.60
13	64QAM	2/3	4.00
14	64QAM	3/4	4.50
15	64QAM	4/5	4.80
16	64QAM	5/6	5.00

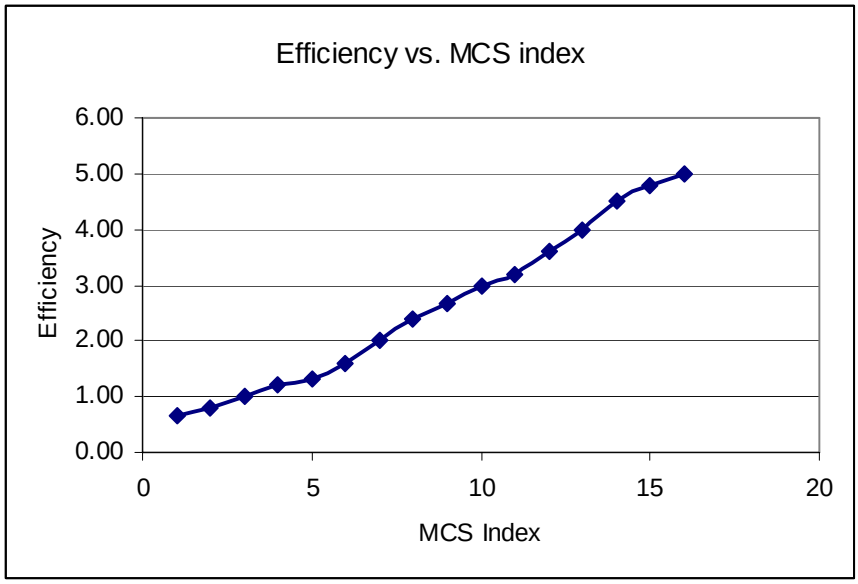

Figure 9 Spectral efficiency and MCS index for SFBC

3.2 MCS with Fixed Block Sizes / SM / 3kmph

In this section, the performances of different MCS sets with fixed block sizes in SM mode are presented. We still used Table 1 as super MCS set needs to be evaluated. It is obvious that SM mode will not work in code rate as low as 1/8, however, to make the comparison complete, and more importantly to see how well SM performs in the low SNR region, we simulated low code rate cases as well. Our objective is to see the relation between SFTD and SM in the low SNR region, e.g. (QPSK, ¼) SFBC vs. (QPSK, 1/8) SM. As can be seen later, although SM does not have advantage in this region, the performance difference between the two are in fact not large (about 1.5 dB, known channel, 640 code block length). This interesting observation tells us that for a distributed channel, with uncorrelated antennas, SM is robust in the low SNR region as well. If SFBC can work, so can SM — with some performance degradation.

The simulated results are shown in Figure 11 — Figure 16. It can be noticed that the trends of the performances for different MCS sets are the same for all the block sizes simulated. In addition, according to the simulation results, an MCS set as shown in Table 3 can be selected. The selection criterion is SNR vs. efficiency. The MCS requires higher operating point than an MCS of equal or higher efficiency will be eliminated. The selected MCS performance curves corresponding to Turbo code block size 640 are given in Figure 17 and Figure 18.

Compared to Table 2, there are three changes in Table 3. One is replacing (16QAM, 2/5) with (16QAM, 3/7); another is replacing (16QAM, ¾) with (64QAM, ½); the third change is removing (16QAM, 4/5). If needed, we may replace it with (64QAM, 5/9). The corresponding per-layer based effective information data rate (bits per QAM × code rate) vs. MCS indexes is shown in Figure 10.

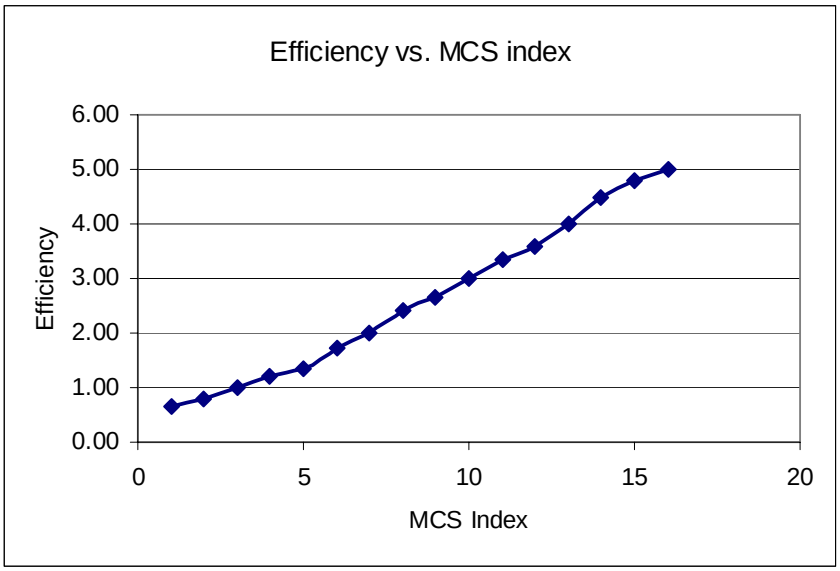

Figure 10 Spectral efficiency and MCS index for SM

Table 3 MCS table based on SM simulation results

MCS	Modulation	Code rate	Efficiency
1	QPSK	1/3	0.67
2	QPSK	2/5	0.80
3	QPSK	1/2	1.00
4	QPSK	3/5	1.20
5	QPSK	2/3	1.33
6	16QAM	3/7	1.71
7	16QAM	1/2	2.00
8	16QAM	3/5	2.40
9	16QAM	2/3	2.67
10	64QAM	1/2	3.00
11[2]	64QAM	5/9	3.33
12	64QAM	3/5	3.60
13	64QAM	2/3	4.00
14	64QAM	3/4	4.50
15	64QAM	4/5	4.80
16	64QAM	5/6	5.00

[2] This MCS can be inserted to make the two MIMO modes have the same number of MCS and same turbo code block sizes.

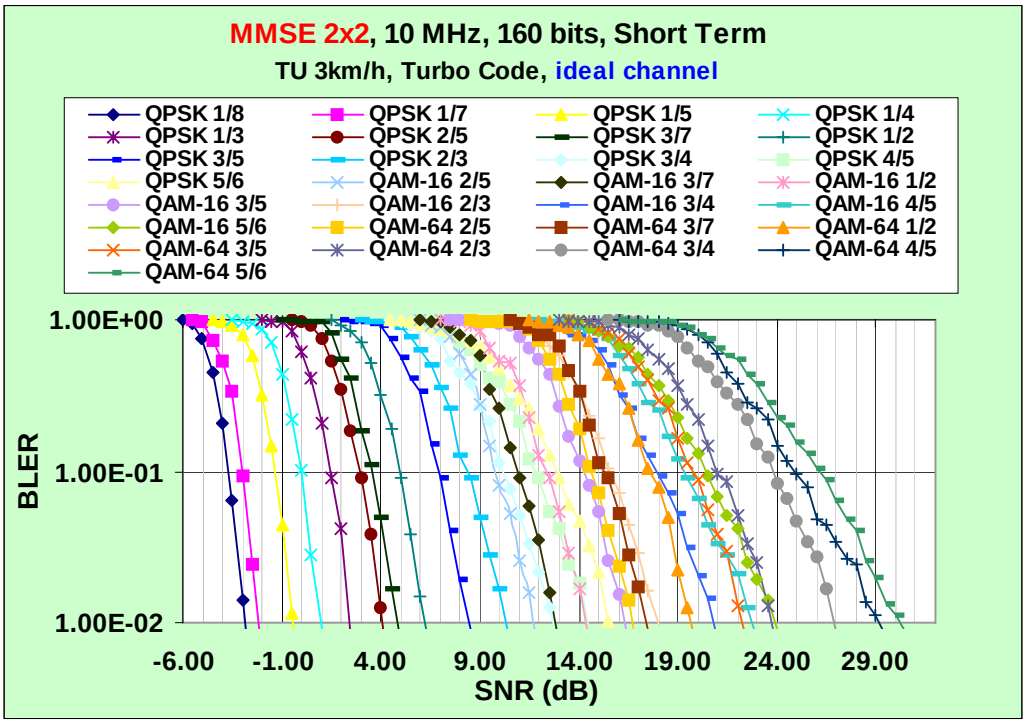

Figure 11 TU known channel, 3kmph, Turbo code block size 160 bits.

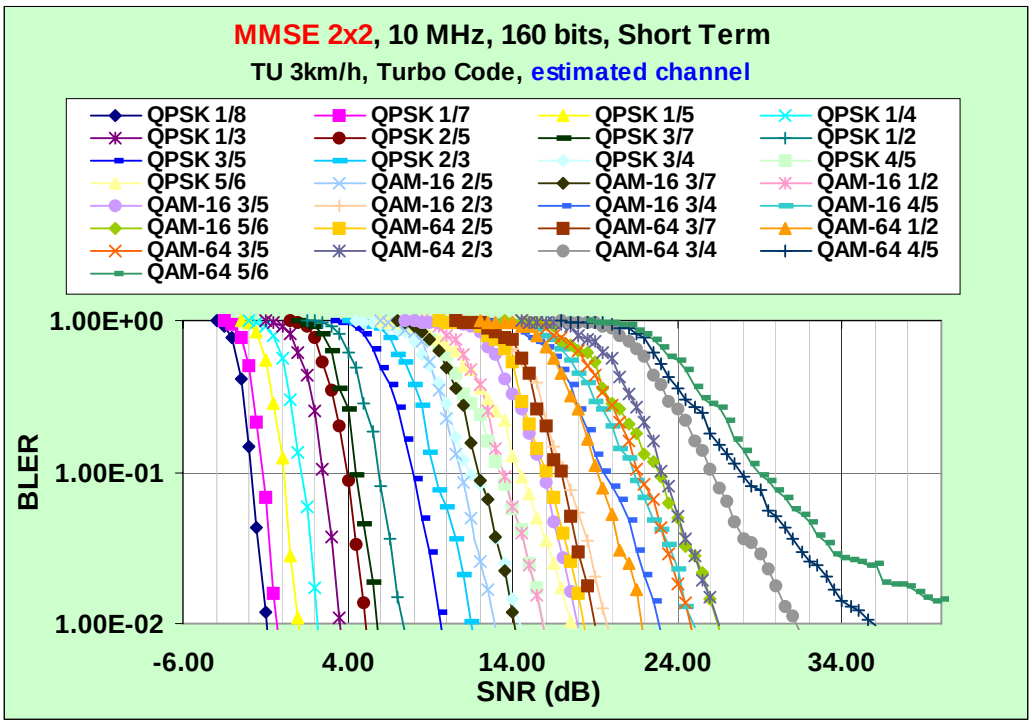

Figure 12 TU estimated channel, 3kmph, Turbo code block size 160 bits.

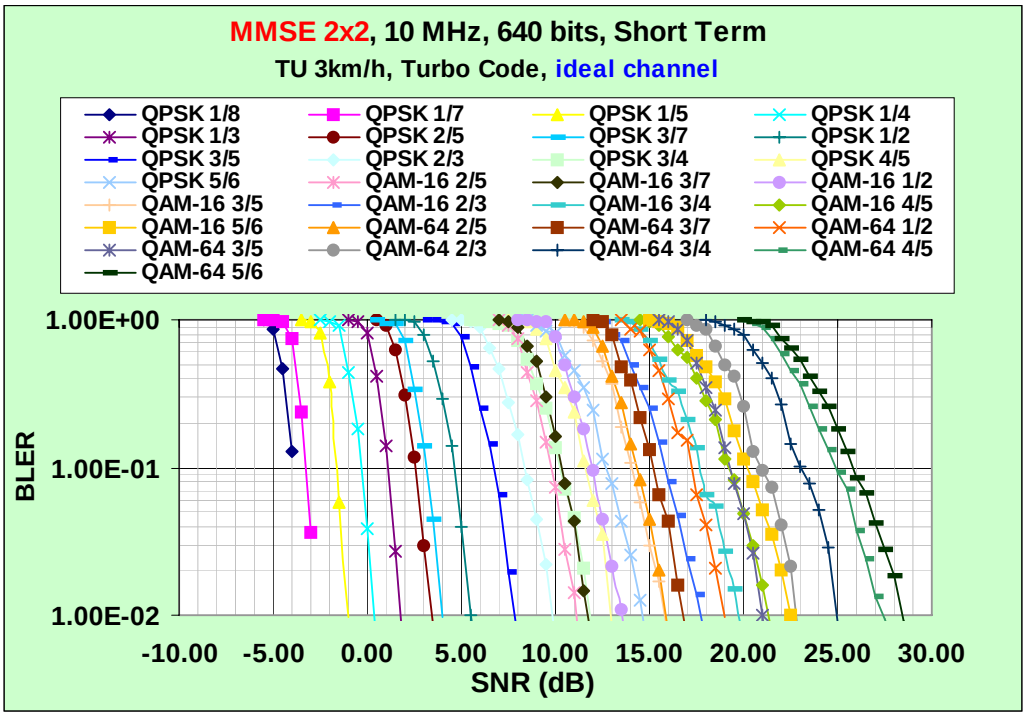

Figure 13 TU known channel, 3kmph, Turbo code block size 640 bits.

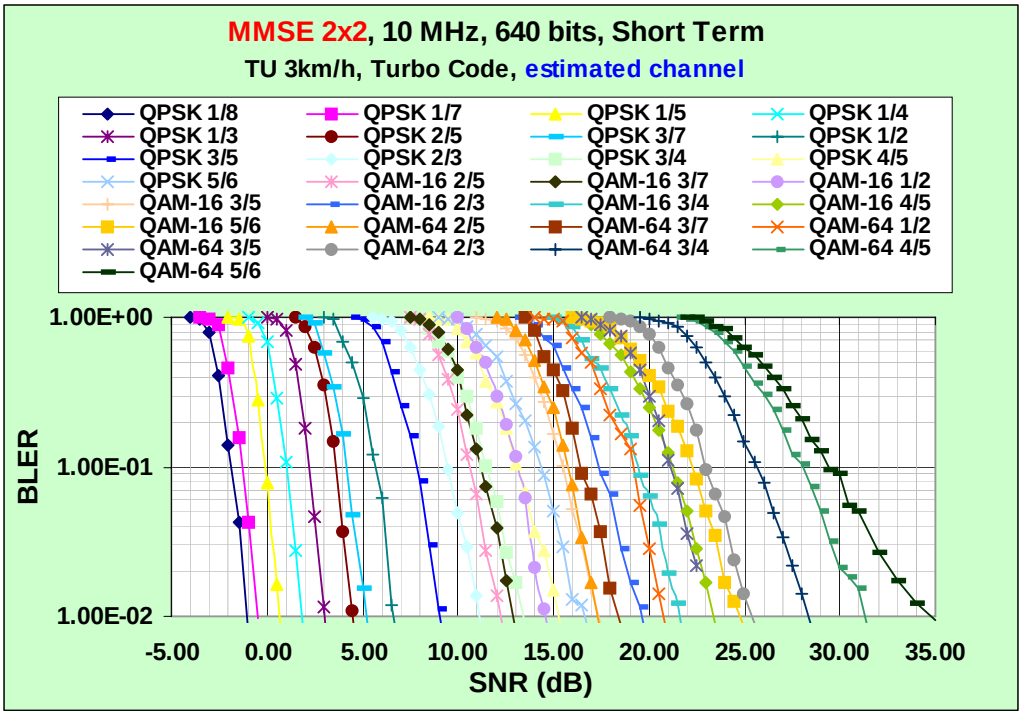

Figure 14 TU estimated channel, 3kmph, Turbo code block size 640 bits.

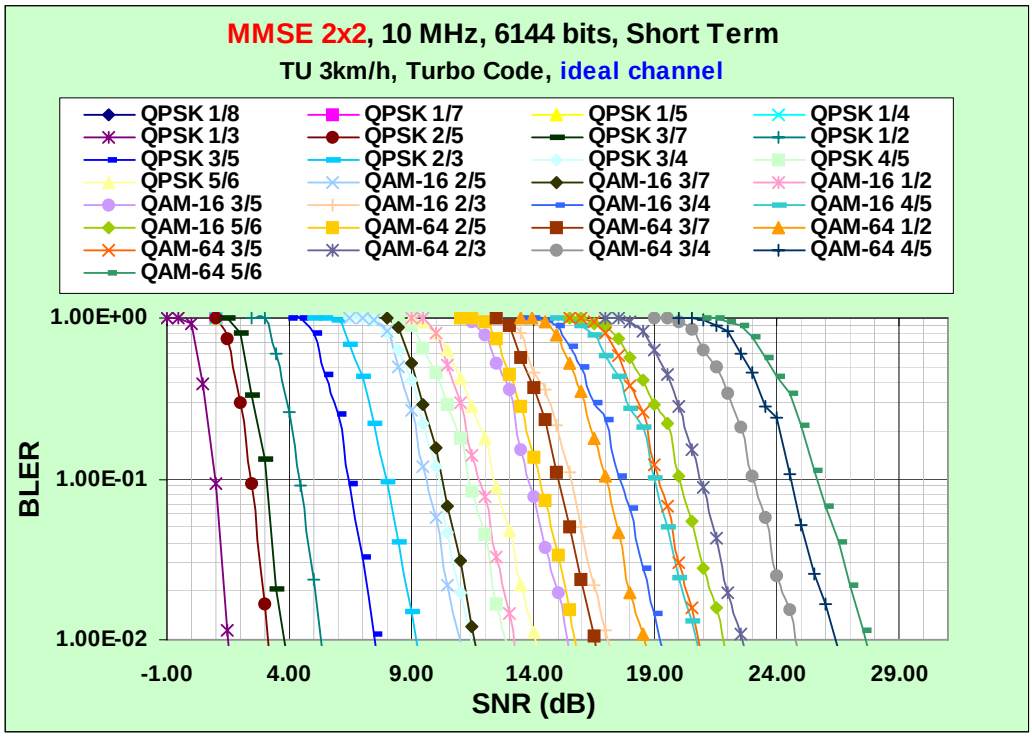

Figure 15 TU known channel, 3kmph, Turbo code block size 6144 bits.

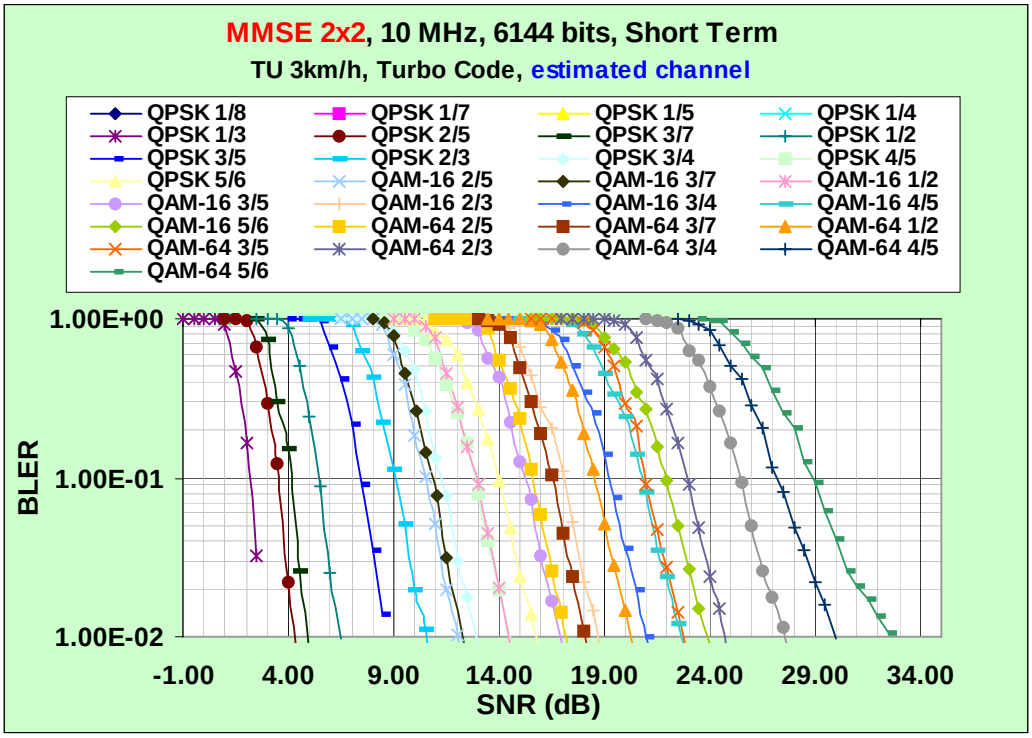

Figure 16 TU estimated channel, 3kmph, Turbo code block size 6144 bits.

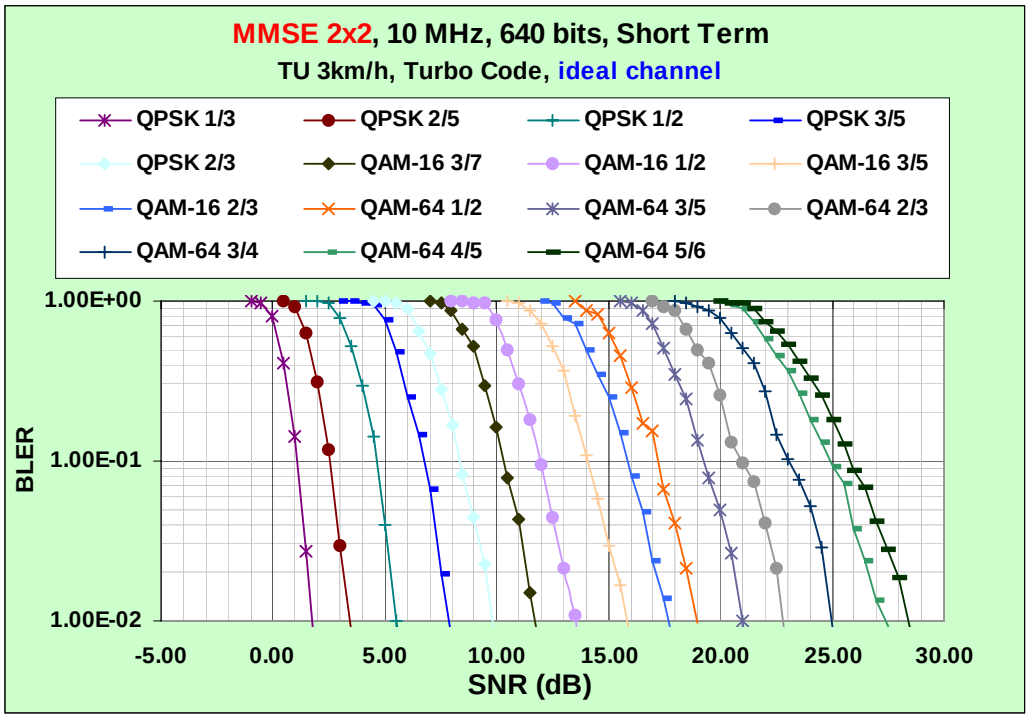

Figure 17 TU MCS set with 15 entries – SM known channel

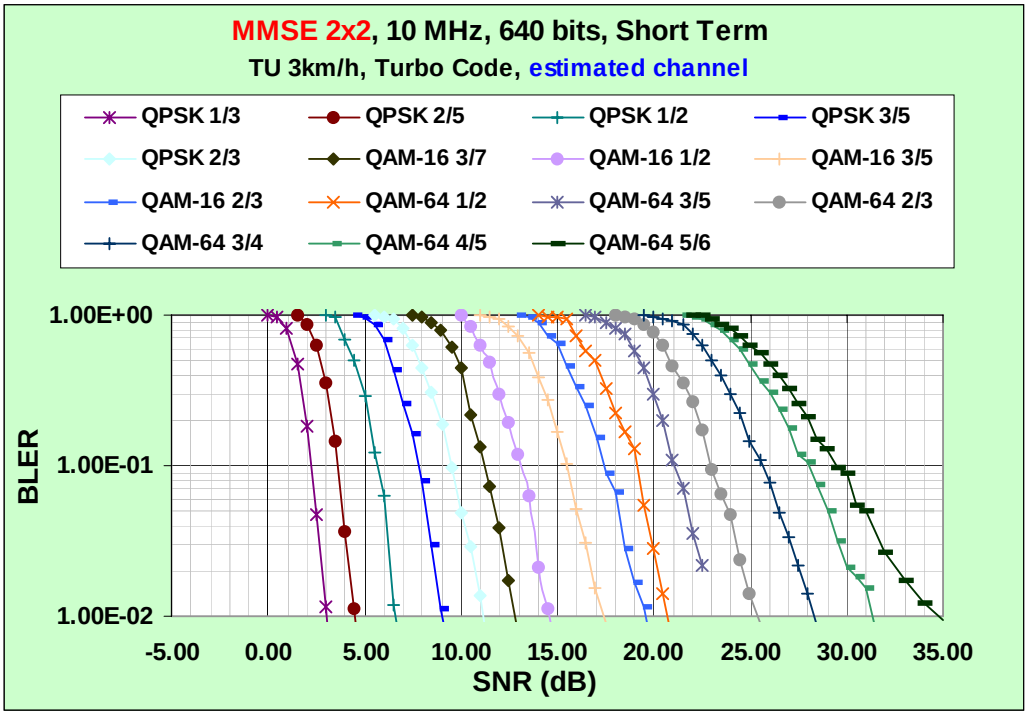

Figure 18 TU MCS set with 15 entries – SM estimated channel

3.3 MCS with Fixed Block Sizes / SFBC / 120kmph

For high moving UE, the link performance depends on many factors: channel estimation, channel aging, channel prediction, just to name a few. Link adaptation is usually difficult, and hence diversity and HARQ become more important.

Since this work is for MCS identification, we assume that although channel changes in time the feedback is instant. The difference between this high mobility case and the nomadic case are:

- In addition to frequency domain fading, we have fading in time, too;
- Larger channel estimation error due to channel variation in time.

The purpose is to verify whether the same set for the nomadic case is applicable to the high mobility case. The simulation results for SFBC with code block length 640 are shown in Figure 19 and Figure 20; and the curves corresponding to Table 2 are shown in Figure 21 and Figure 22. It is noticed that Figure 21 and Figure 22 have very similar distributions as Figure 7 and Figure 8. This means that when the feedback is instant, indeed the same MCS set is applicable to both high mobility and nomadic UEs.

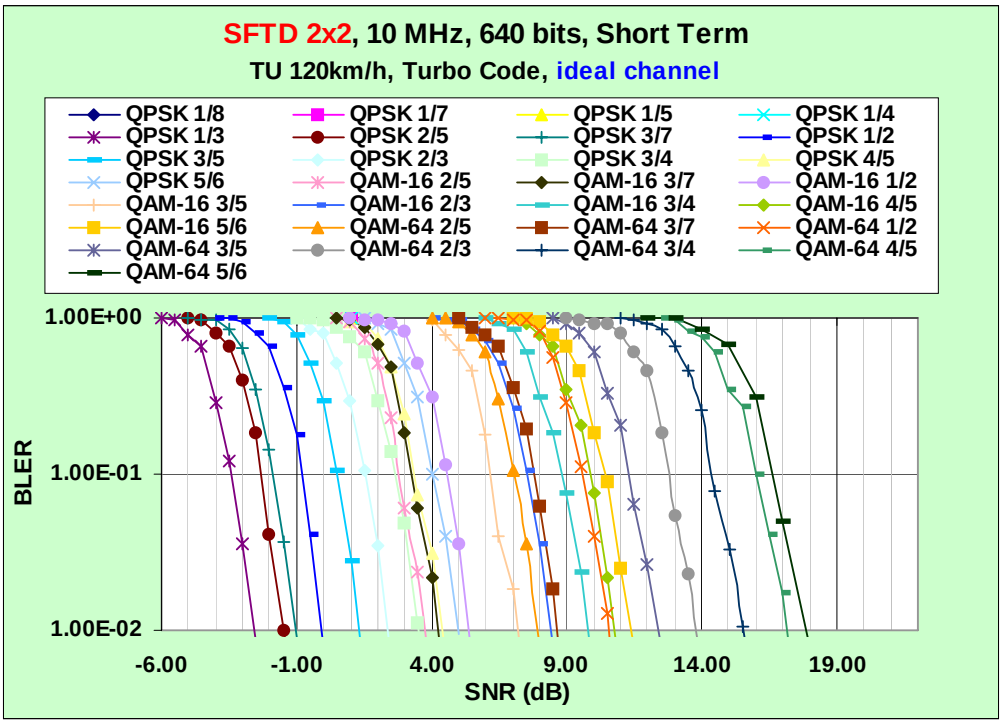

Figure 19 TU known channel 120kmph, SFBC, Turbo code block size 640 bits

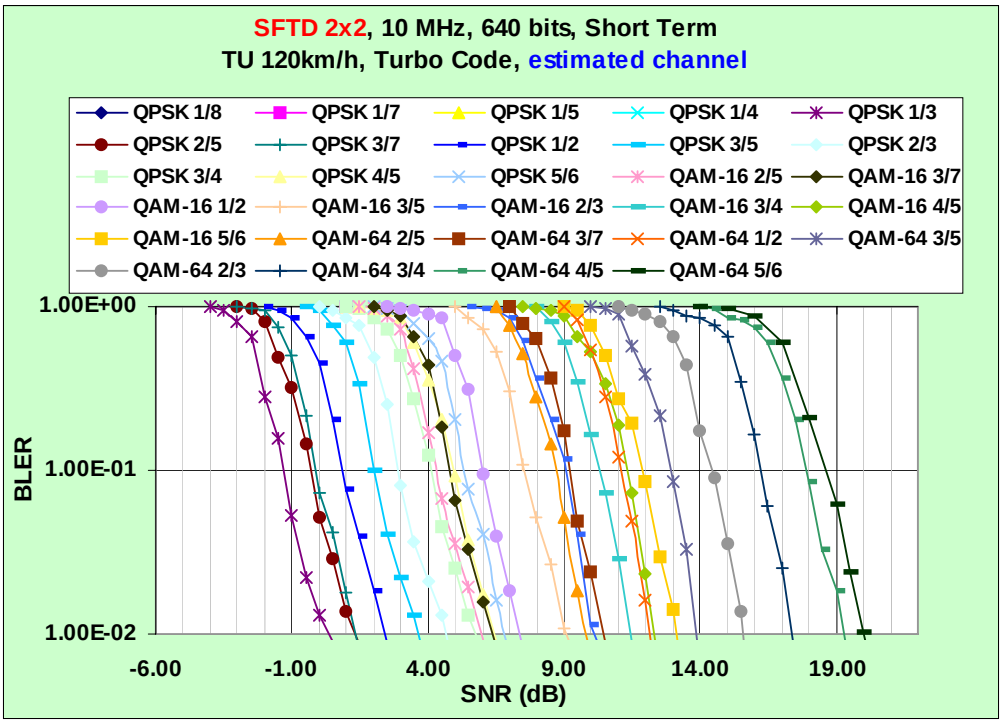

Figure 20 TU estimated channel 120kmph, SFBC, Turbo code block size 640 bits

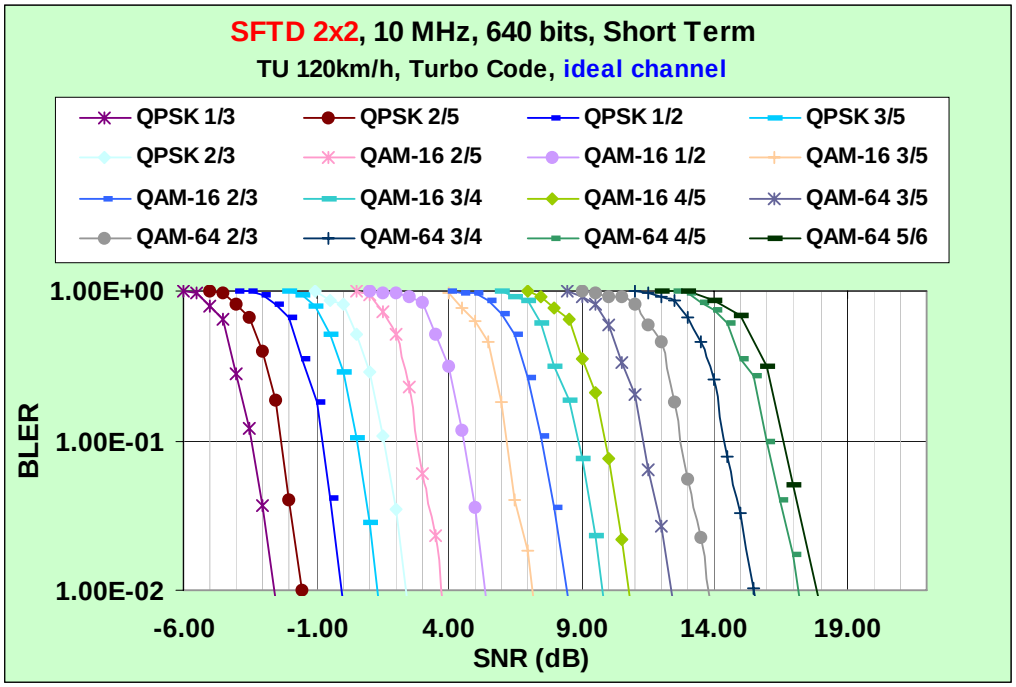

Figure 21 MCS set with 16 entries – SFBC 120kmph known channel

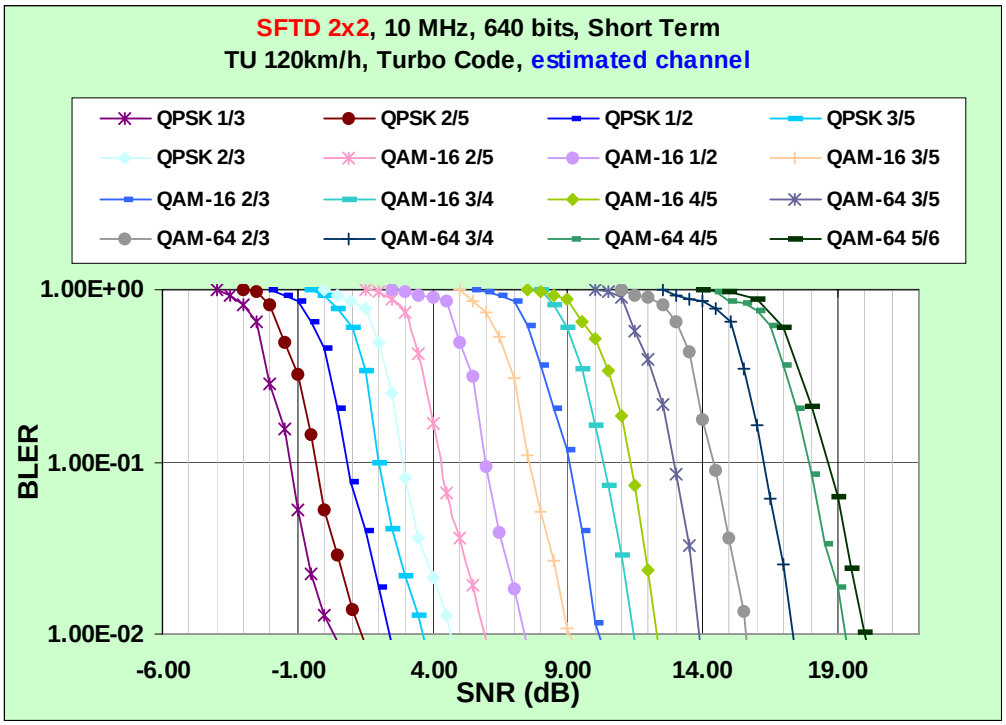

Figure 22 MCS set with 16 entries – SFBC 120kmph estimated channel

3.4 MCS with Fixed Block Sizes / SM / 120kmph

The simulation results for SM with code length 640 are shown in Figure 23 and Figure 24. Comparing Figure 23 and Figure 24 with Figure 13 and Figure 14, we can see that speed up to 120km/h does not have much impact on the link level performance. Similarly, curves corresponding to Table 2 are shown in Figure 25 and Figure 26. Again, by comparing Figure 25 and Figure 26 we can see that they are very close to Figure 17 and Figure 18.

With these results we may conclude:

- The same MCS set can be applied to both nomadic and high mobility cases;
- The adaptive channel estimation algorithm (with 3rd order Lagrange polynomial interpolation) works very well.

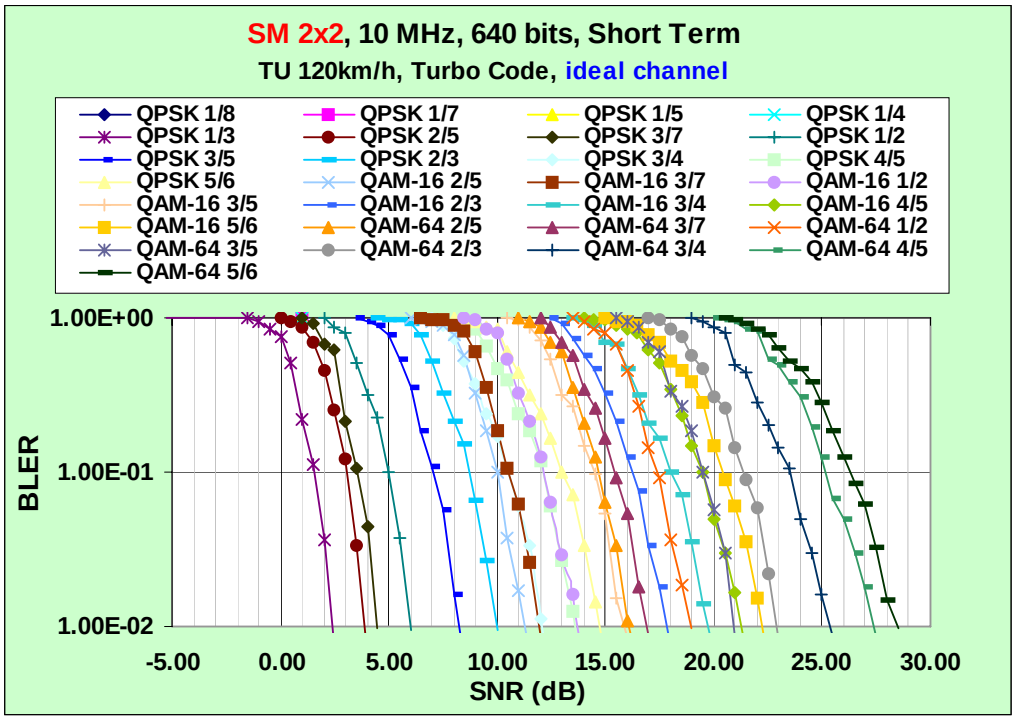

Figure 23 TU known channel 120kmph, SM, Turbo code block size 640 bits

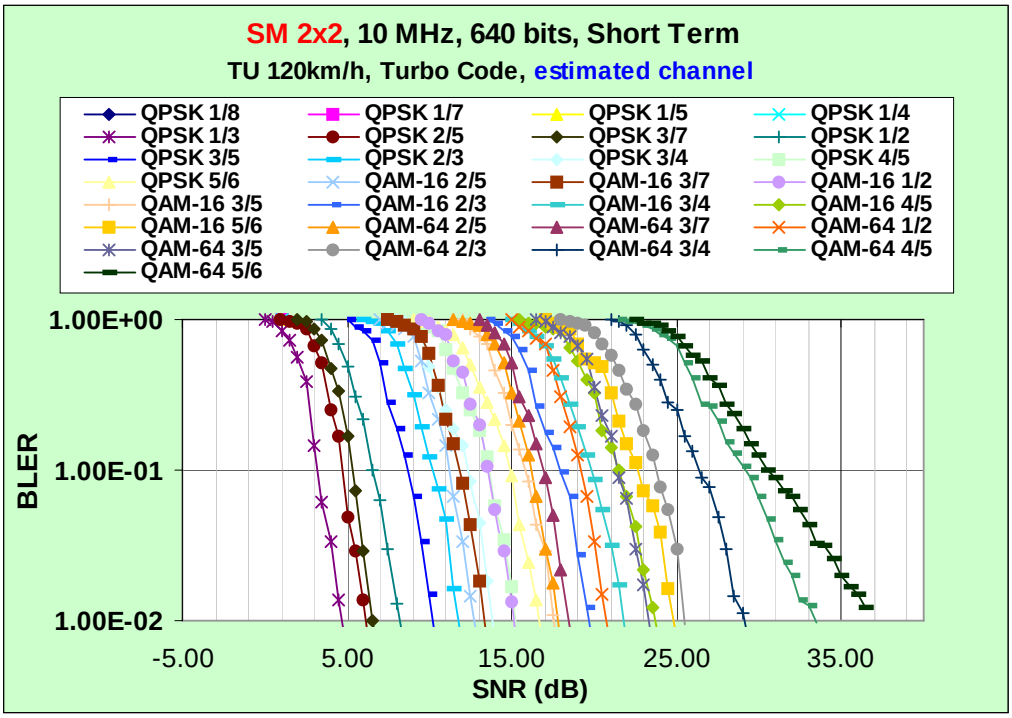

Figure 24 TU known channel 120kmph, SM, Turbo code block size 640 bits

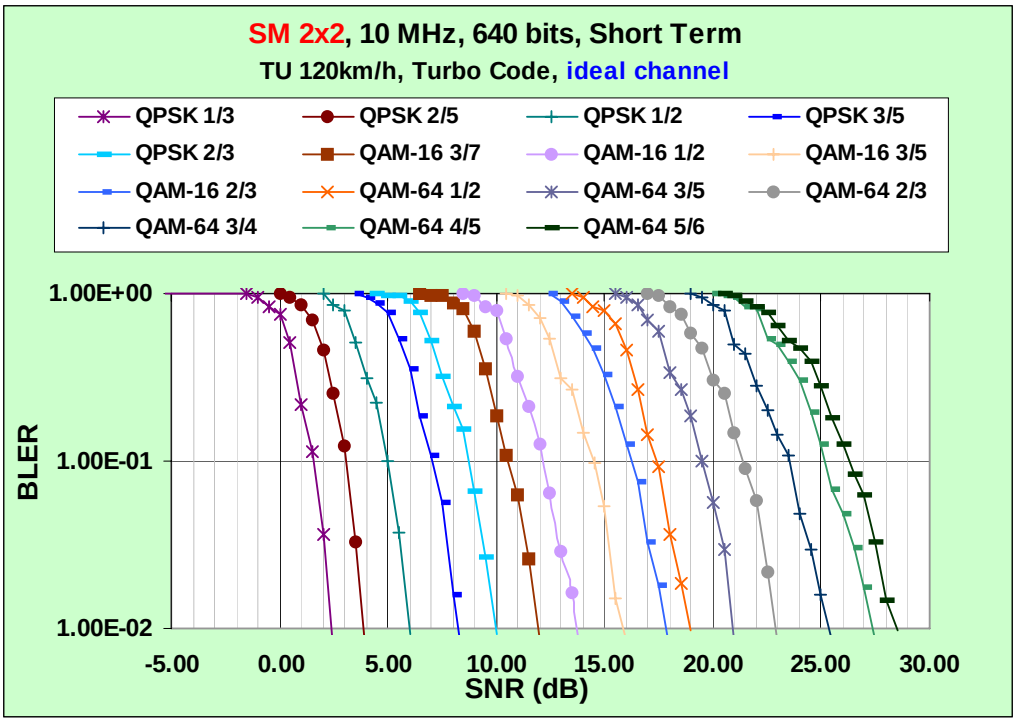

Figure 25 MCS set with 15 entries – SM 120kmph known channel

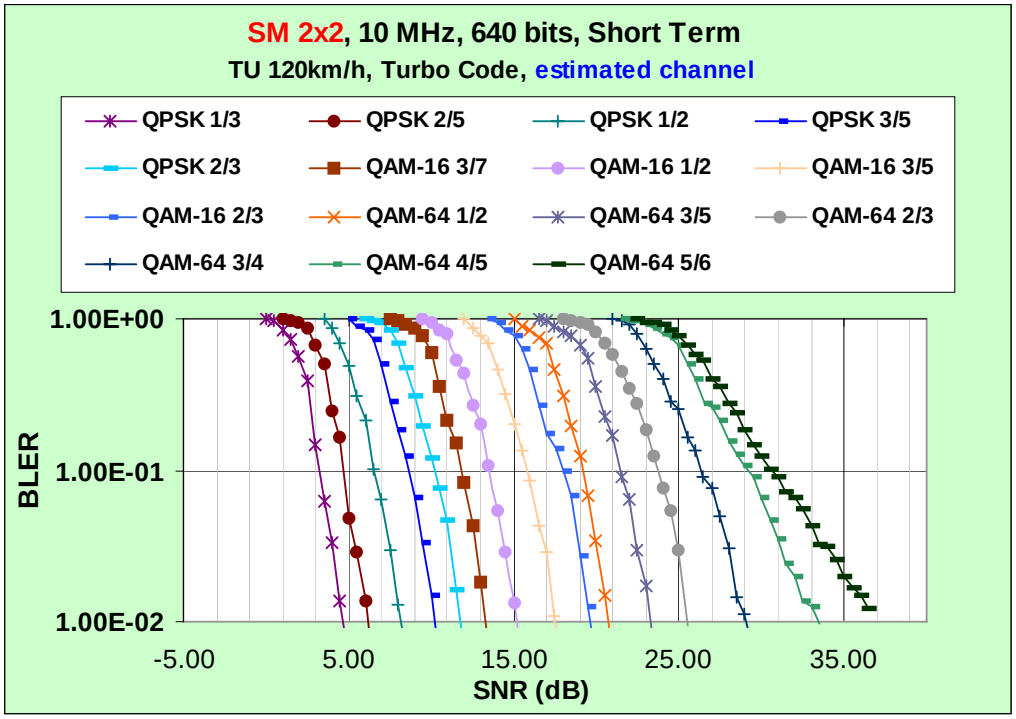

Figure 26 MCS set with 15 entries – SM 120kmph estimated channel

3.5 MCS with Different Block Sizes

It is well known that Turbo codes have larger coding gain over larger size code blocks. Given a CQI (or MCS in this matter) feedback, the scheduler needs to know the required SNR for different blocks. As explained earlier, LTE specifies total 188 block sizes, but it is not necessary for us to simulate them all. We selected 160, 640, and 6144, in total three sizes, for this exercise.

The SNR delta distribution for each selected MCS set is given in Figure 27—Figure 40. In most cases, the coding gain difference between the smallest and largest code blocks is about 1.0 dB. This suggests that since in TU channel frequency diversity plays a more important role, coding gain differences due to different code block sizes are less significant.

4 Summary

In this contribution, simulation results for different MCS candidates were presented, with considerations of

- Different MIMO modes (i.e. SFBC and SM);
- Different vehicle speed (3km/h and 120 km/h);
- Perfectly known channel and estimated channel;
- Different FEC code block sizes.

The results show that for LTE distributed channel, Table 2 and Table 3 provides evenly distributed performances in terms of SNR for STBC and SM, and can well be used for adaptive modulation and coding (AMC) as well as future system level simulation.

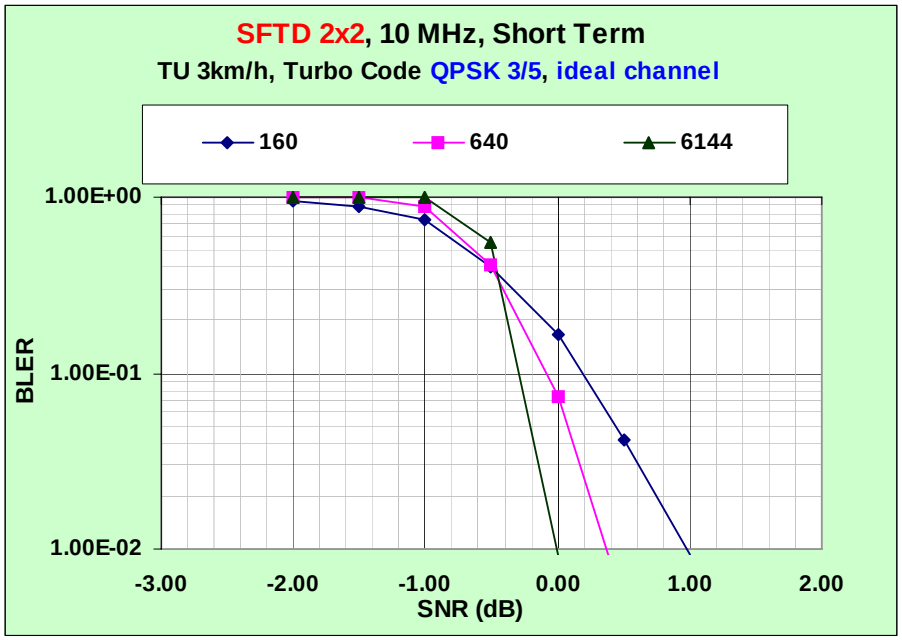

Figure 27 Coding gain delta for known channel – SFBC, QPSK 3/5

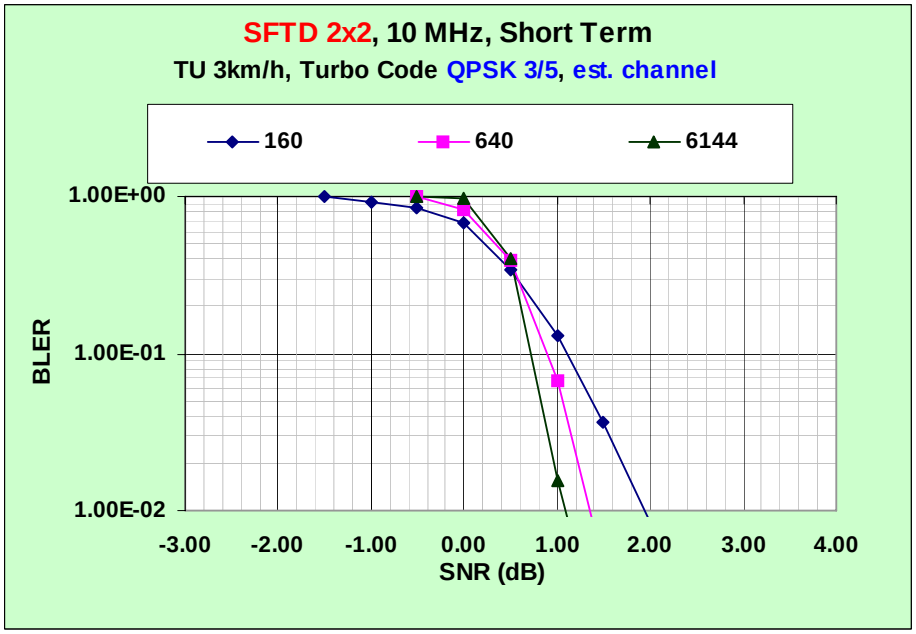

Figure 28 Coding gain delta for estimated channel – SFBC, QPSK 3/5

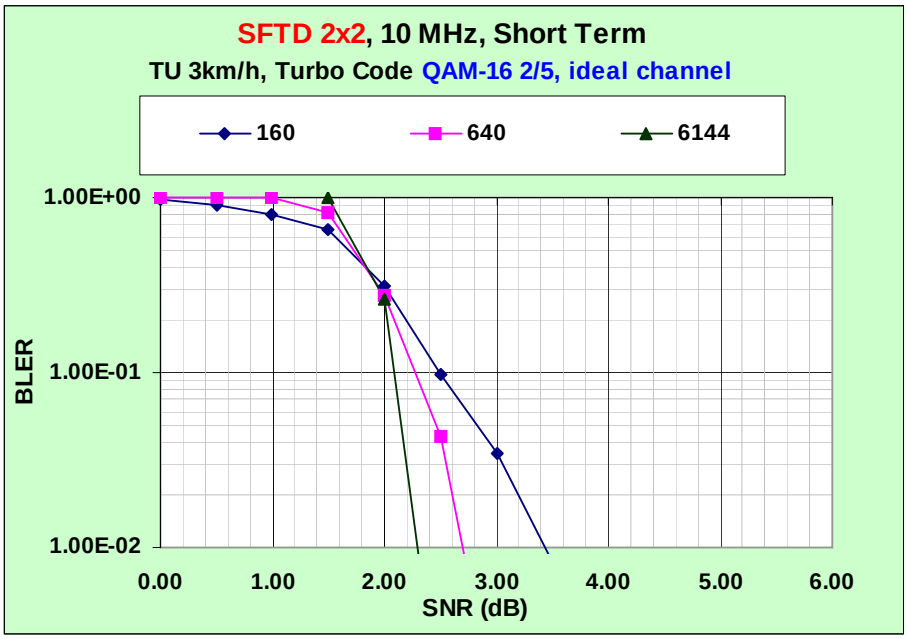

Figure 29 Coding gain delta for known channel – 16QAM 2/5

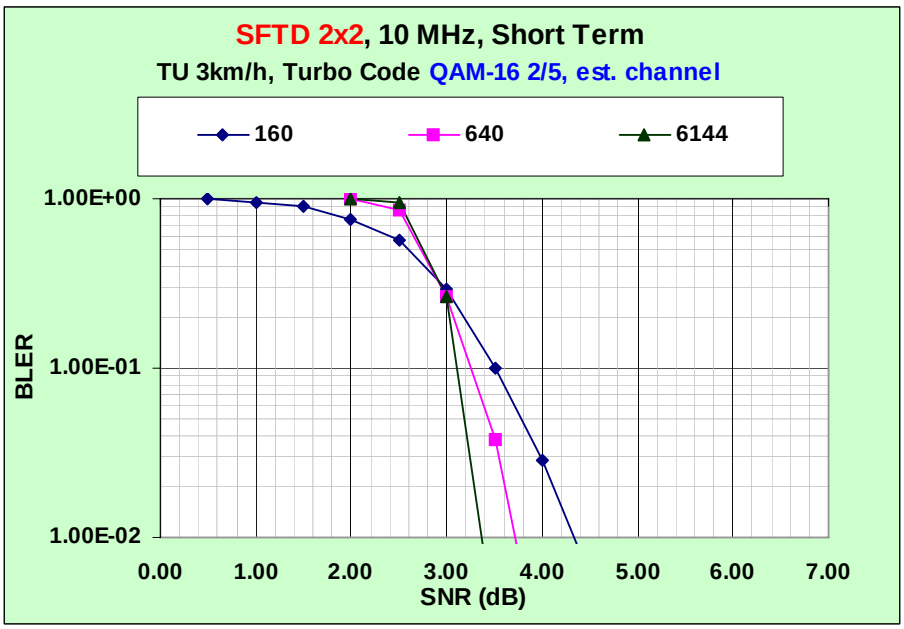

Figure 30 Coding gain delta for estimated channel - 16QAM 2/5

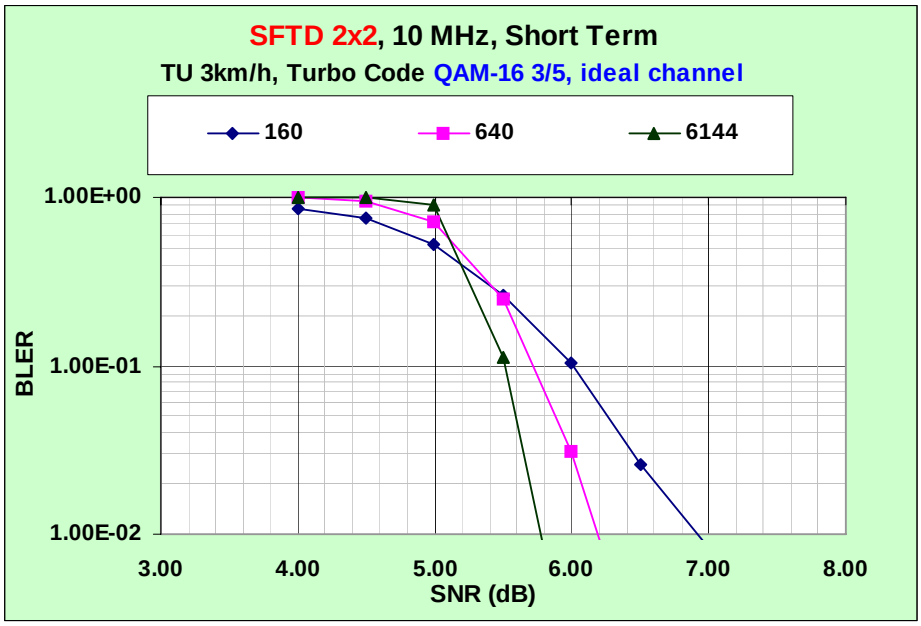

Figure 31 Coding gain delta for known channel - 16QAM 3/5

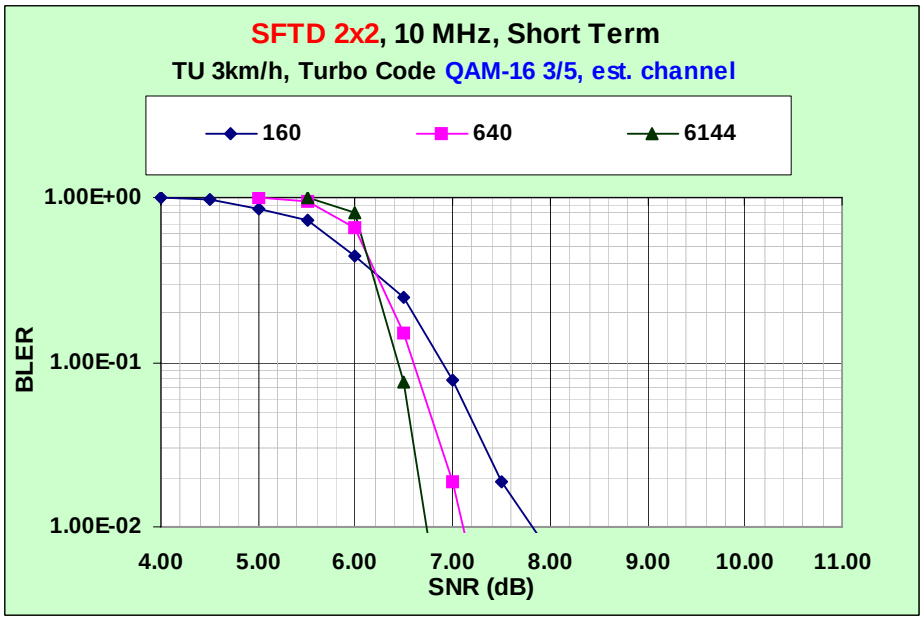

Figure 32 Coding gain delta for estimated channel - 16QAM 3/5

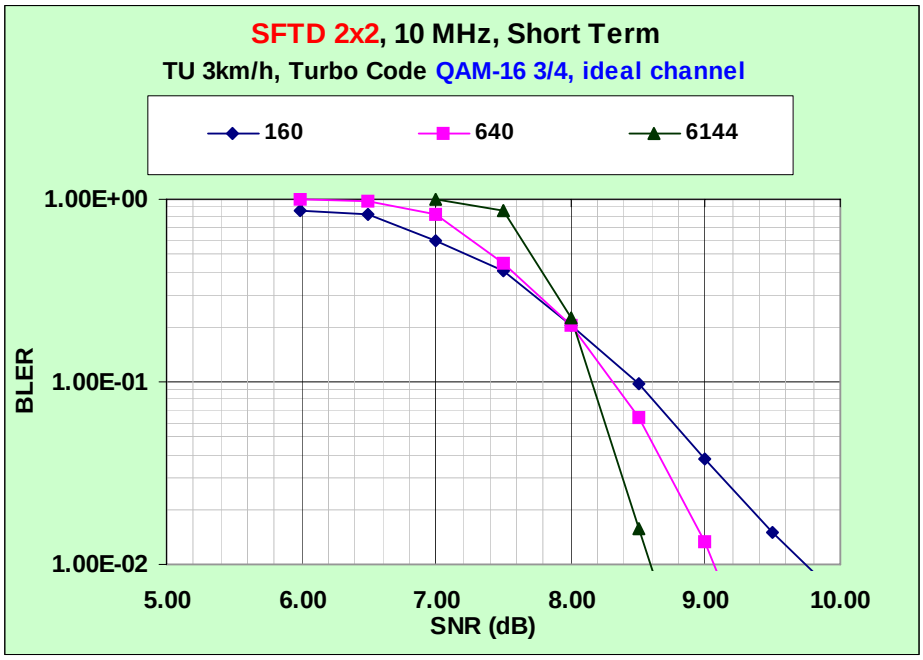

Figure 33 Coding gain delta for known channel - 16QAM 3/4

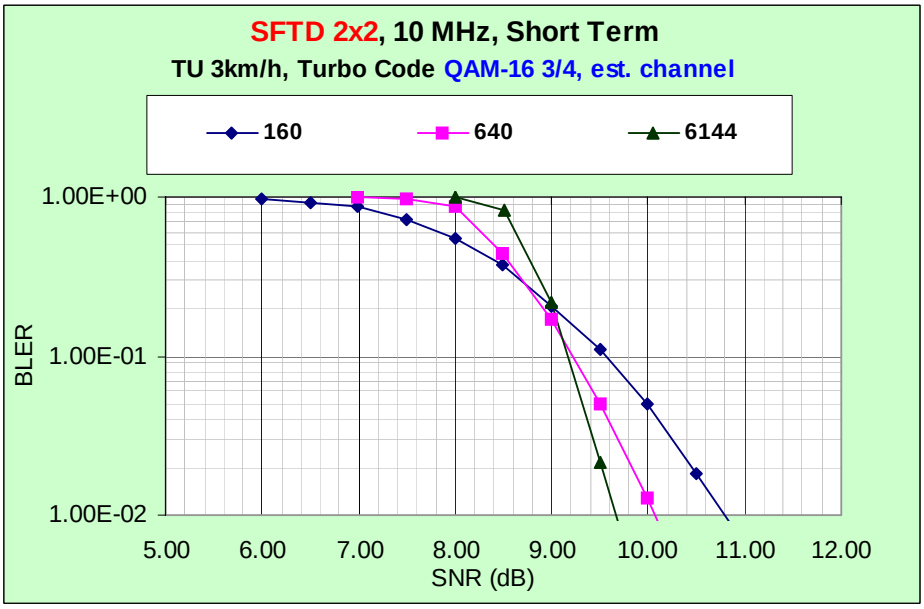

Figure 34 Coding gain delta for estimated channel - 16QAM 3/4

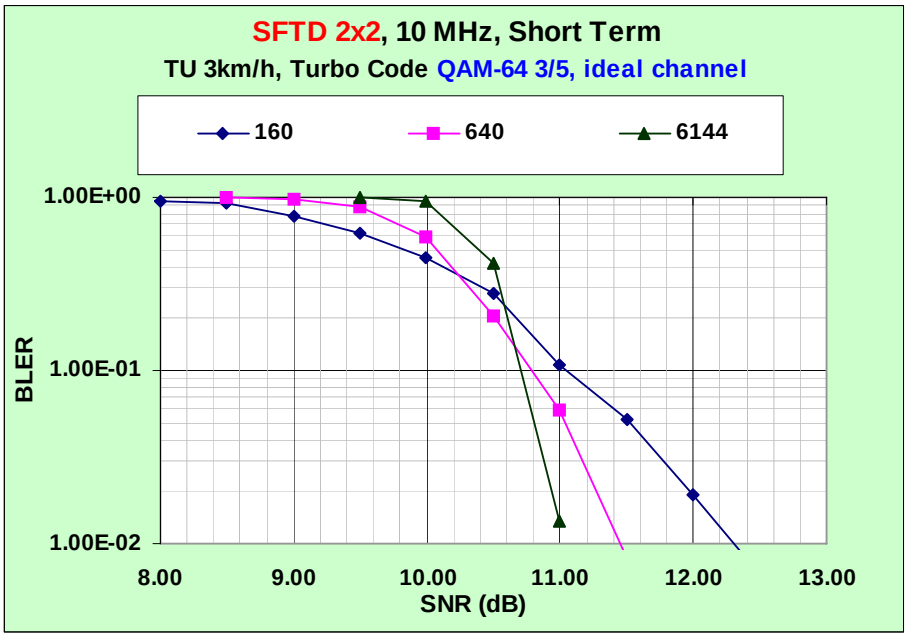

Figure 35 Coding gain delta for known channel - 64QAM 3/5

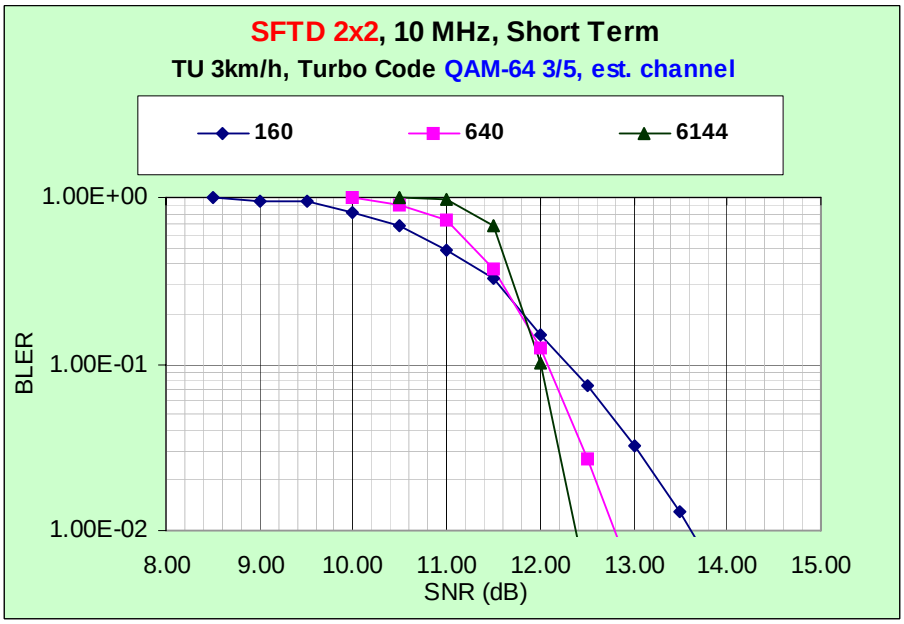

Figure 36 Coding gain delta for estimated channel - 64QAM 3/5

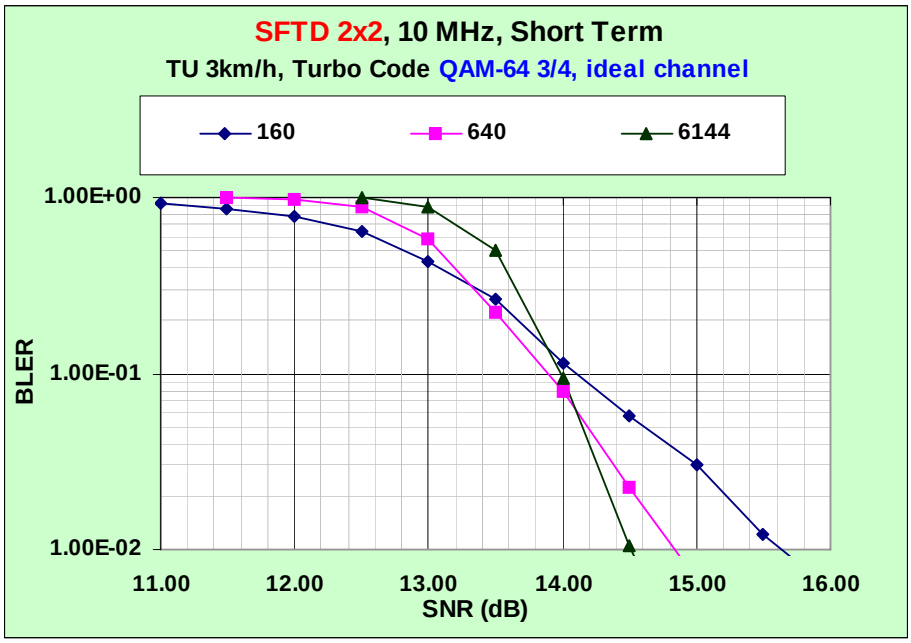

Figure 37 Coding gain delta for known channel, SFBC, 64QAM ¾

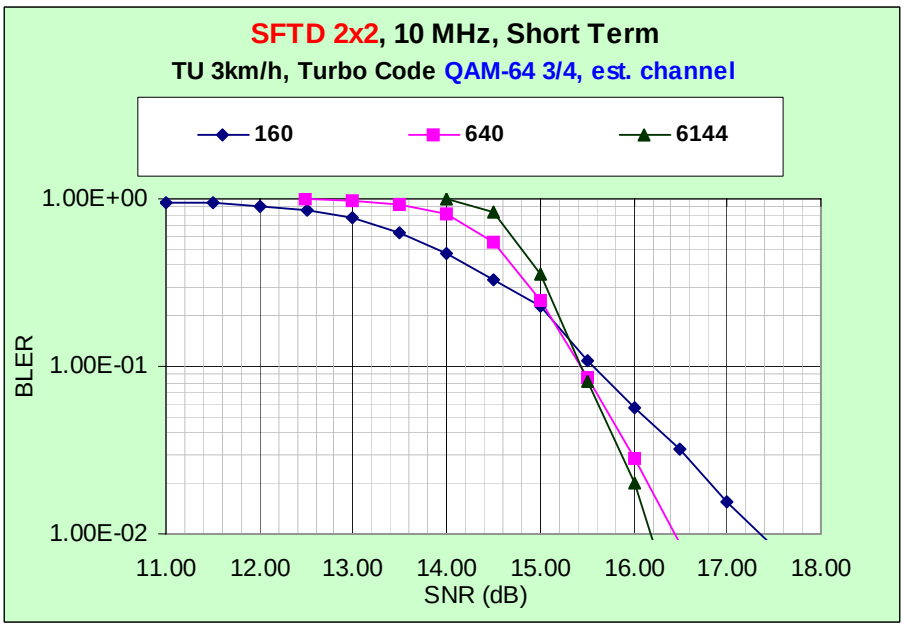

Figure 38 Coding gain delta for estimated channel, SFBC, 64QAM ¾

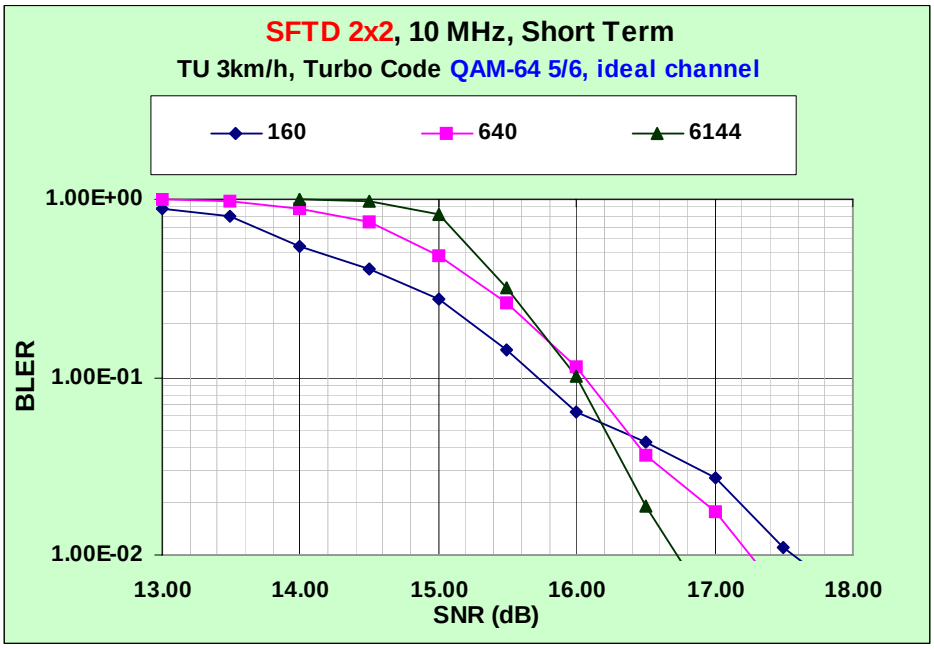

Figure 39 Coding gain delta for known channel – SFBC, 64QAM 5/6

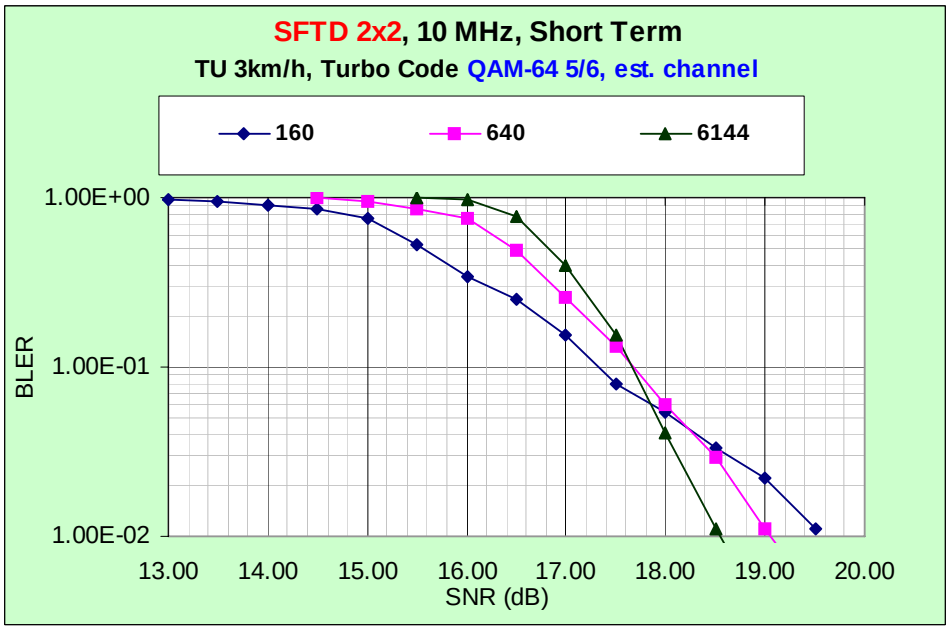

Figure 40 Coding gain delta for estimated channel - SFBC, 64QAM 5/6