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Title: Performance Results for OTFS Modulation

Agenda item: 7.1.3.1

Document for: Discussion

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1. Introduction

A number of different proposals have been presented in 3GPP as candidate waveforms for the New Radio RAT. In [1], a Way Forward was supported by several companies that includes simulation assumptions for the evaluation of the different waveforms. These evaluation assumptions and parameters are mainly focused on the use cases of coexistence of different services and/or numerologies on the same channel. They therefore focus on the attributes of the waveform that affect performance in these cases, such as emissions, guard-band, CP and other overheard, etc.

In this paper, we evaluate the performance of OTFS (Orthogonal Time Frequency Space), a novel modulation technique presented in [2], [3]. OTFS modulation is a scheme that comprises of a 2-D FFT based preprocessing block on top of an OFDM or other multicarrier system resulting in improved performance. As such, OTFS can operate on top of OFDM or any of the OFDM variants proposed like windowed OFDM, filtered OFDM, zero-tail OFDM, unique-word OFDM etc. In particular, many of the aspects of the OTFS waveform, like out of channel emissions etc., are determined by the choice of OFDM flavor for the underlying multicarrier system and not by the 2-D FFT based pre-processing block. For this reason, in this paper we focus our comparisons on the performance advantages of OTFS (especially in the presence of Doppler), and less on the questions of co-existence. In other words, we focus on the single numerology case rather than the mixed numerology case. Once there is some preliminary agreement on the OFDM variant that seems more promising, we will present OTFS emissions etc. results using that variant as the underlying multicarrier technology with single and mixed numerology. In future submission, we will further present OTFS performance under additional numerologies of 30/60 kHz sub-carrier spacing.

The results in the next section show that OTFS outperforms OFDM and is especially well suited for the high-mobility use case.

2. Simulation Results

We evaluate the performance of OTFS versus OFDM for a SISO system on a carrier frequency of 4 GHz and vehicle speeds of 3 Km/h and 120 Km/h (11 Hz and 444 Hz max Doppler spread) as dictated by [1]. We further study the high-speed train use case with speeds close to 500 Km/h (1820 Hz max Doppler spread). We use ideal channel estimation and no control overhead in this comparison to focus on the performance of the modulation. We use an ML receiver for OFDM (which in this SISO case reduces to an MMSE receiver) and a turbo equalizer for OTFS. The turbo equalizer iterates between the decoder and the linear equalizer improving the performance in each iteration. For the SISO case the turbo equalizer is more complex than the ML/MMSE OFDM equalizer; as the MIMO order grows however, the turbo complexity compares favorably to the OFDM ML equalizer.

Table 1 summarizes the simulation parameters.

Table 1: Simulation Parameters

Parameter	Value
Carrier frequency	4 GHz
System BW	10 MHz
TTI length	1 msec

Subcarrier spacing	15 KHz
FFT size	1024
CP length	4.7 usec
Receiver	OTFS: Turbo equalizer, OFDM: ML/MMSE
Coding	Turbo code, 6144 max code-block length
MCS	16 QAM 2/3, 16-QAM 3/4, QPSK 3/4
Control overhead	No overhead
Channel estimation	Ideal
Channel	EVA-11, EVA-444, EVA-1820 (3, 120, 500 Km/h)

The first three figures depict BLER curves for 16 QAM, rate 3/4 MCS. Figure 1 and Figure 2 depict the performance for 11 Hz and 444 Hz max Doppler spread respectively, while Figure 3 shows the performance for the high mobility 1820 Hz max Doppler spread channel. Notice that OTFS outperforms OFDM in all cases with significant improvement in the high mobility case. However, as shown in Figure 3, OFDM fails for this MCS (and 15 KHz subcarrier spacing) at this very high mobility case; OTFS is much better but also marginal. A better comparison can be drawn from lower MCS levels as explained next.

We evaluate the performance at a lower MCS where OFDM can handle the high mobility impairments. Figure 4, Figure 5 and Figure 6 show similar results for 16 QAM, rate 2/3 MCS. Notice that in this case as well, OTFS provides significant gains in the high-speed case (close to 6 dB at 0.1 BLER) as shown in Figure 6. The reason for the poor OFDM performance here is the extreme ICI (the Doppler spread is 12% of the subcarrier spacing). The reason for the better performance of the OTFS system is the better handling of the ICI by the combination of the OTFS transform and turbo equalizer structure.

Finally, we evaluate the performance of an even lower MCS of QPSK, rate 3/4. The results are shown in Figure 7, Figure 8 and Figure 9 where OTFS again outperforms OFDM. Table 2 summarizes the OTFS gains for each scenario at a BLER of 1e-1.

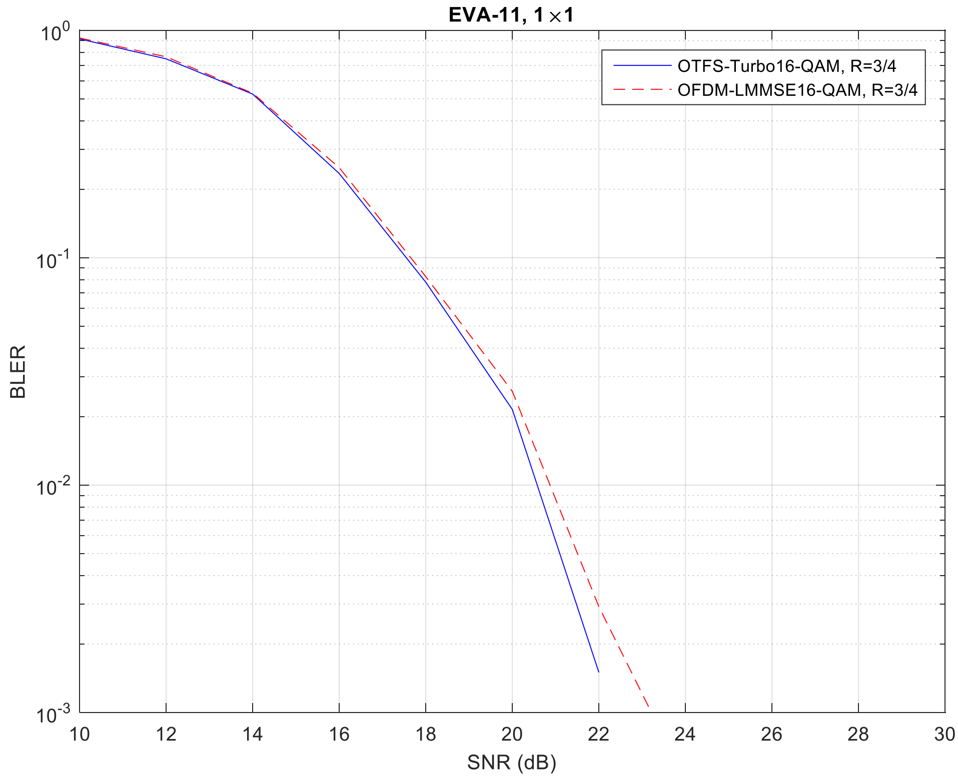

Figure 1: BLER Curves for 16QAM R3/4 1x1 on EVA-11 Channel

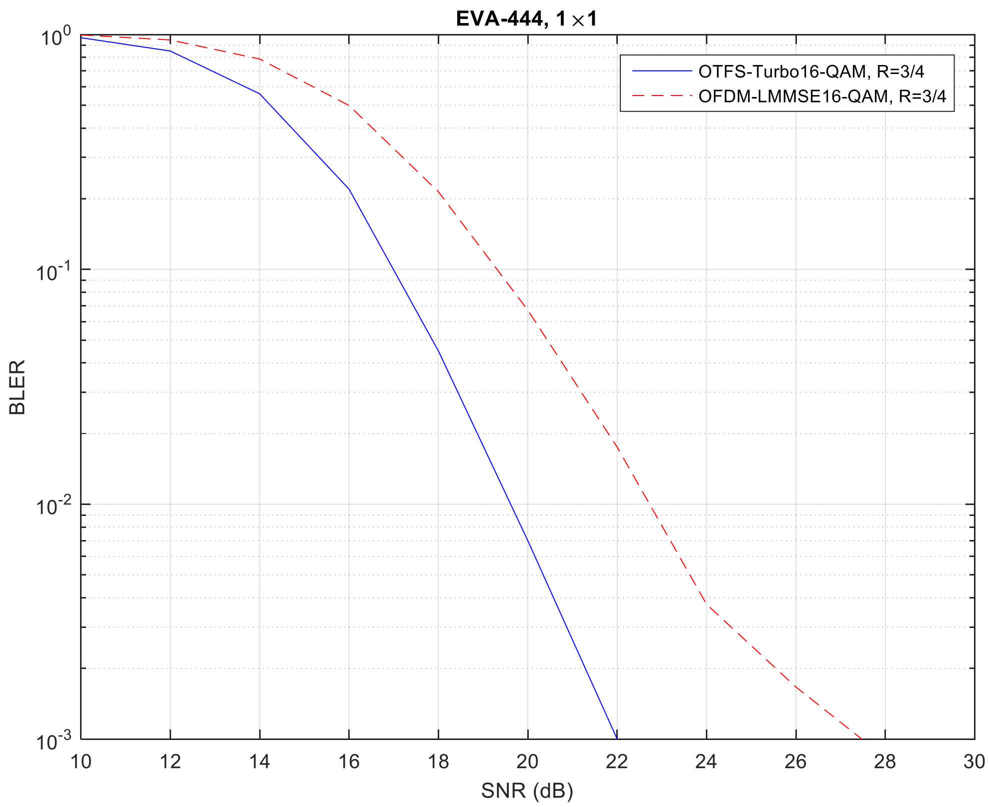

Figure 2: BLER Curves for 16QAM R3/4 1x1 on EVA-444 Channel

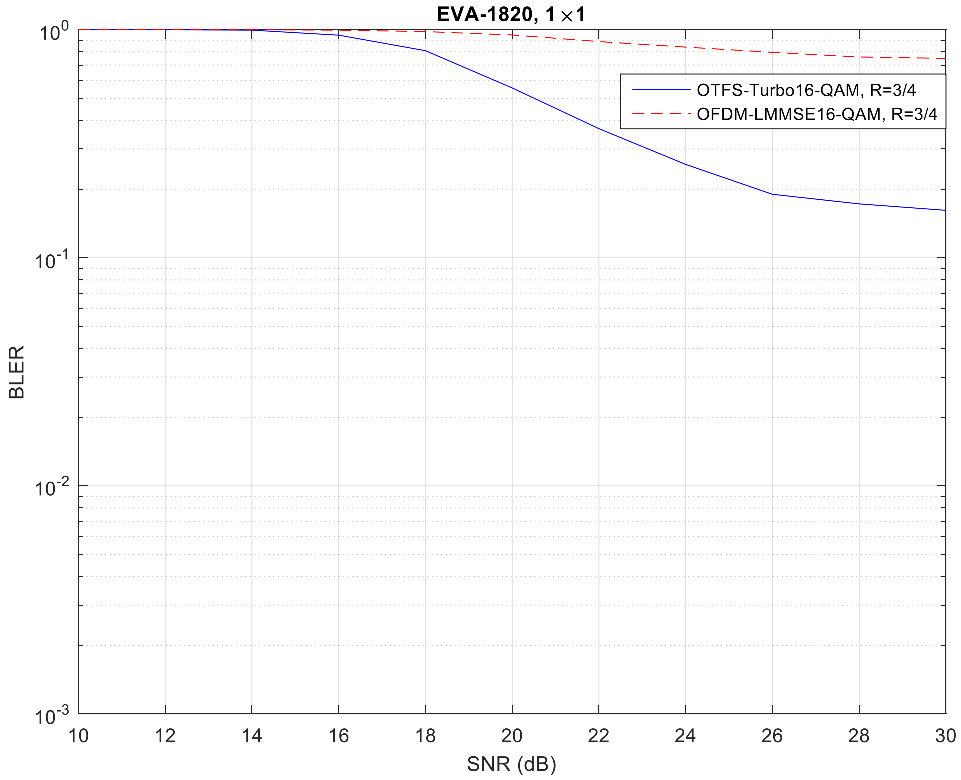

Figure 3: BLER Curves for 16QAM R3/4 1x1 on EVA-1820 Channel

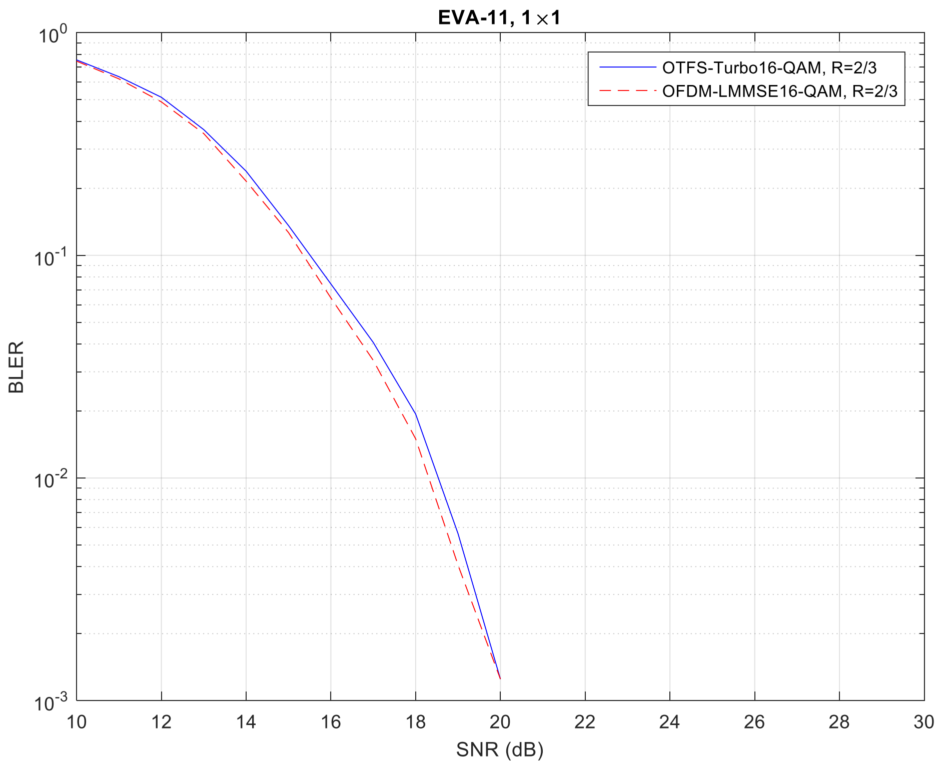

Figure 4: BLER Curves for 16QAM R2/3 1x1 on EVA-11 Channel

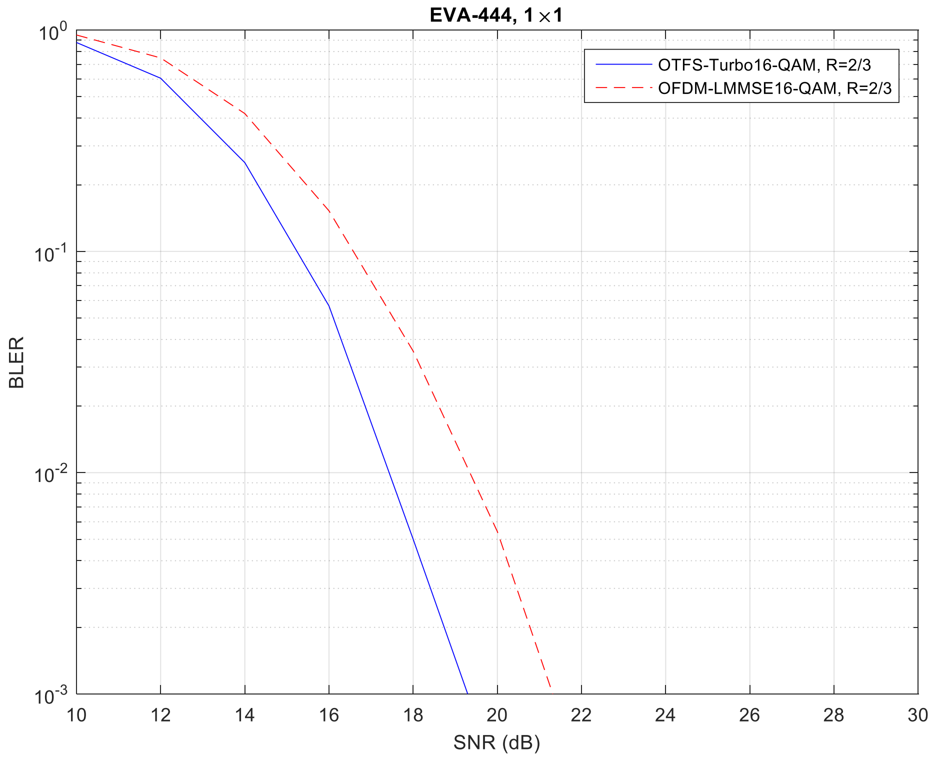

Figure 5: BLER Curves for 16QAM R2/3 1x1 on EVA-444 Channel

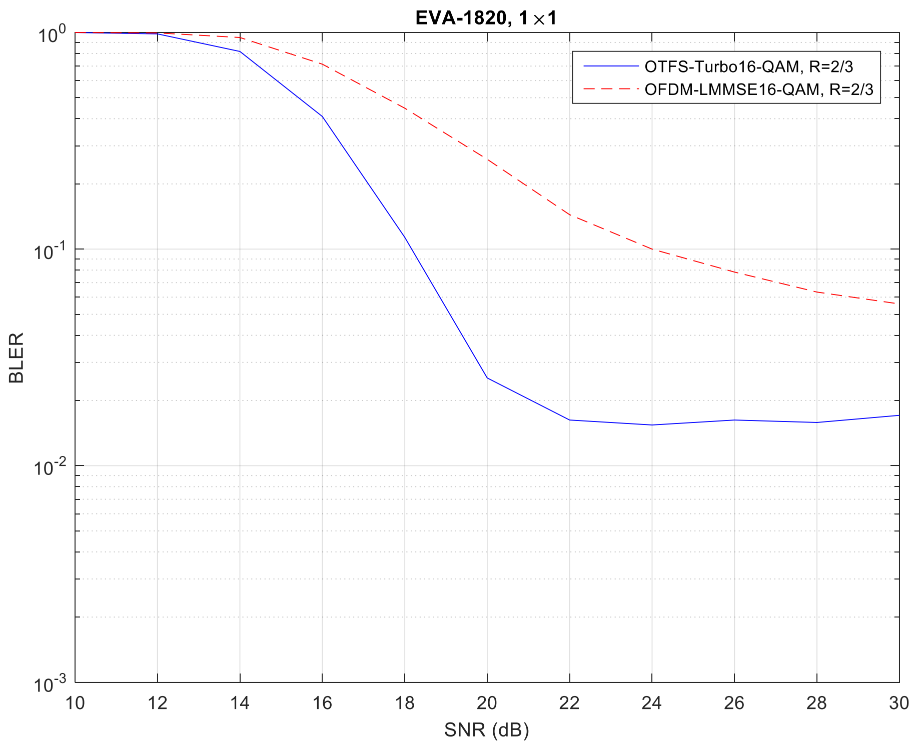

Figure 6: BLER Curves for 16QAM R2/3 1x1 on EVA-1820 Channel

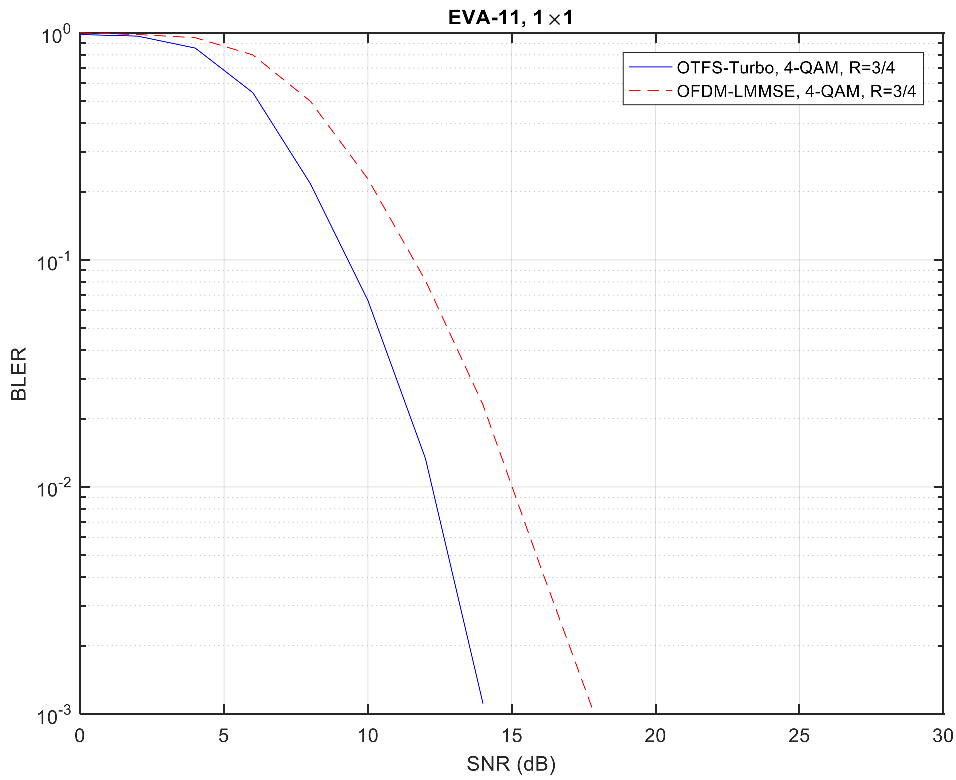

Figure 7: BLER Curves for QPSK R3/4 1x1 on EVA-11 Channel

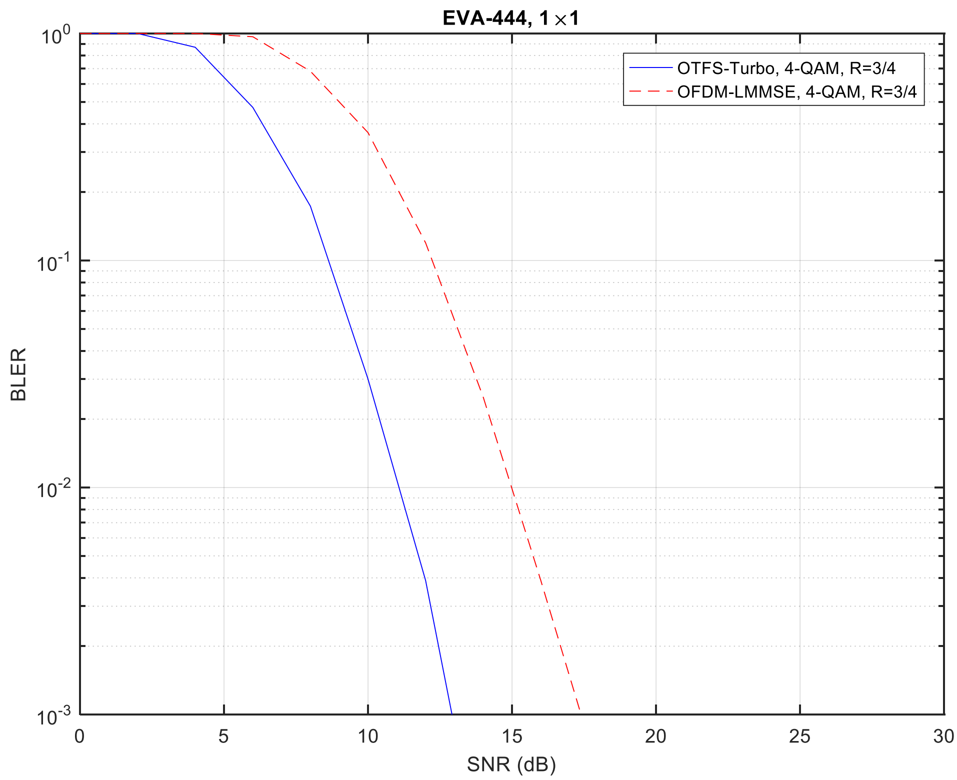

Figure 8: BLER Curves for QPSK R3/4 1x1 on EVA-444 Channel

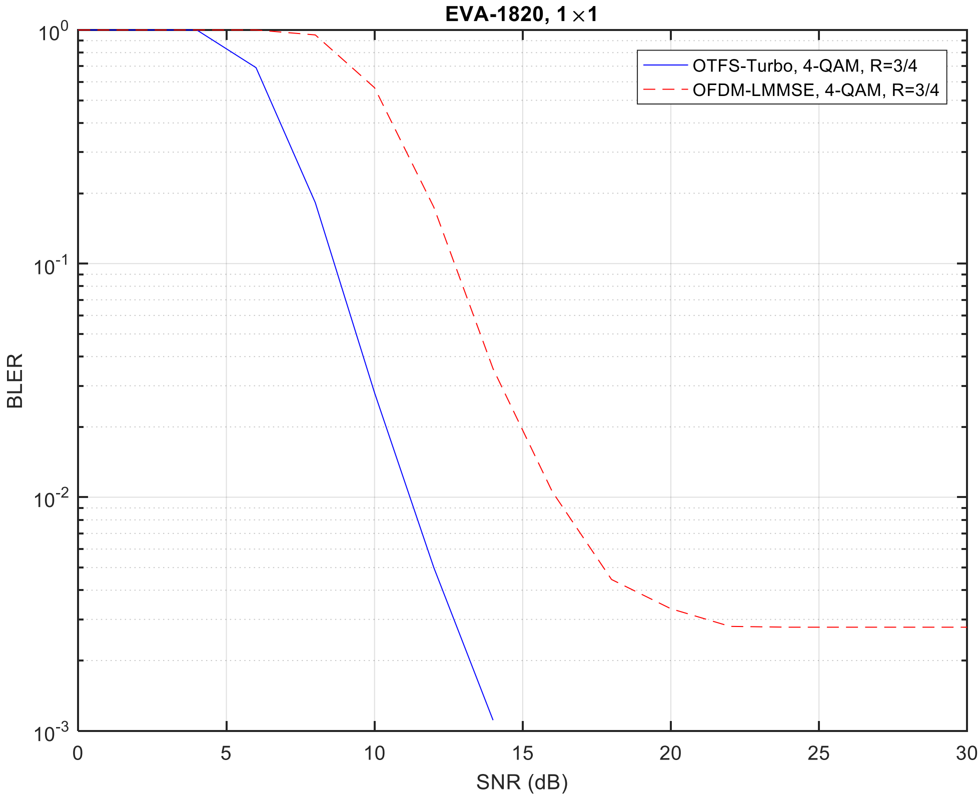

Figure 9: BLER Curves for QPSK R3/4 1x1 on EVA-1820 Channel

Table 2: OTFS vs OFDM Performance Difference at BLER = 0.1

	EVA-11	EVA-444	EVA-1820
QPSK R 3/4	2.3 dB	3.6 dB	4.1 dB
16 QAM R2/3	0 dB	1.4 dB	5.9 dB
16 QAM R 3/4	0 dB	3.3 dB	N/A

3. Conclusion

The performance comparisons in this paper indicate the superior performance of OTFS especially in the high mobility (high speed train) use case; 6 dB improvement or more is seen at vehicle speeds of 500 Km/h. This kind of improvement can allow high throughput operation in high mobility cases without requiring increasing the subcarrier spacing and incurring the increased CP overhead associated with a larger subcarrier spacing.

4. References

[1] R1-163558 "WF on evaluation assumptions for waveform", Source: Huawei, HiSilicon, [NTT DOCOMO], [Nokia], [Intel], [MediaTek], [Samsung], [LGE], [Ericsson], [QualComm], [Sony], [Cohere]

[2] R1-162930 "OTFS Modulation Waveform and Reference Signals for New RAT," Source: Cohere Technologies

[3] R1-162929, "Overview of OTFS Waveform for Next Generation RAT," Source: Cohere Technologies