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Source: Cohere Technologies

Title: Performance evaluation of OTFS waveform in single user scenarios

Agenda item: 8.1.2.1

Document for: Discussion

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1. Introduction

Several candidate waveforms for NR have been presented and discussed at the past two RAN1 meetings. For evaluation purposes, it was agreed to study these candidate waveforms under the NR deployment scenarios of single and mixed numerologies on the same carrier. In a previous contribution [1] we presented preliminary performance evaluations comparing the Orthogonal Time Frequency Space modulation to OFDM for the single numerology case. This contribution provides further evaluations, including preliminary MIMO evaluations, comparing OTFS and OFDM.

2. Discussion

For brevity, we would not describe the OTFS modulation in detail herein but refer the reader to a comprehensive treatment in [2]. Our evaluation methodology largely follows the simulation assumptions agreed in [3] for the single user scenarios. In [3] the main objective is to evaluate candidate waveforms that target coexistence of different services and/or numerologies on the same carrier. Accordingly, the evaluation criteria include the user spectral efficiency with respect to the allocated bandwidth (including guard bands for coexistence), PSD with/without clipping, EVM and PAPR/Cubic Metric. In contrast, OTFS modulation may be viewed as a generalization of SCFDM, wherein, a 2D-FFT-based preprocessing block is added on top of an OFDM or other multicarrier system. As such, OTFS can operate in conjunction with a post-FFT processing block such as a window function or a filter to address scenarios with mixed numerologies, or simply to minimize the guard bands needed to meet a spectral mask requirement. Therefore, this contribution focuses on the relative performance of OTFS compared to OFDM in a doubly-selective fading channel. Furthermore, we also present our preliminary findings on MIMO performance.

In line with [3], ideal channel estimation is adopted with no pilot or control overhead. We investigate performance in moderate and high UE speeds of 30 and 120 km/h respectively for the TDL-C channel with RMS delay spread of 300ns. For MIMO, we adopt a constant modulus open loop precoding scheme as this is more realistic for moderate and high speeds. Specifically, for OFDM we use Large-Delay CDD per LTE Transmission Mode 3, whereas OTFS uses an identity precoder. Other simulation assumptions are described in Table 1 of the Appendix.

Figure 1 shows the performance for a 1x1 system at a moderate UE speed of 30 km/h. This is the Case 1a scenario of [3] where the target UE is allocated the entire bandwidth of 50 RBs in 10MHz. For a code rate of ½, it can be seen that OTFS has a 1dB gain over OFDM at the BLER operating point of 10^{-1} for 16QAM, but has similar performance to OFDM for 64QAM. In contrast Figure 2, shows that OTFS performance improves relative to OFDM for the same case of 64QAM when the speed is increased to 120 km/h. Specifically, OTFS has a performance advantage of 2.1dB for 64 QAM. Furthermore, comparing Figure 1 and Figure 2 it can be seen that OTFS gain over OFDM also increases to 2.9 dB for 16QAM. This verifies one of the main benefits of OFTS, namely, its robustness to Doppler effects.

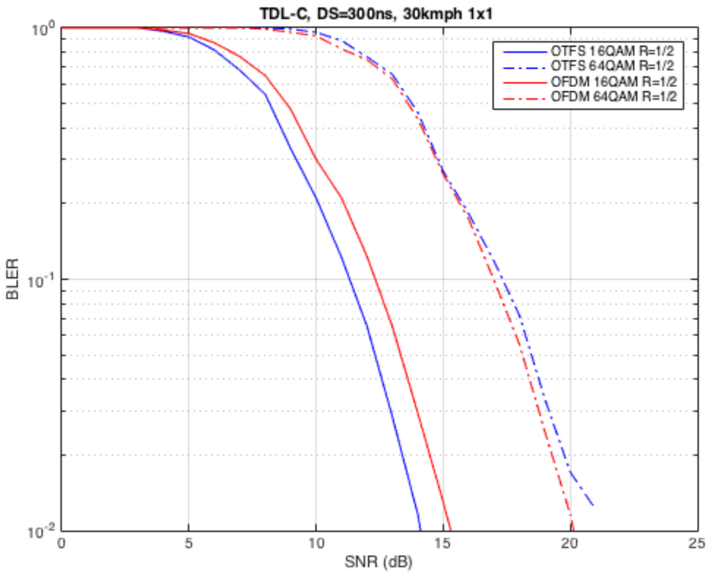

Figure 1: BLER performance for Case 1a, 1x1, 16QAM and 64QAM, R=1/2, 30kmph in TDL-C, DS=300ns channel

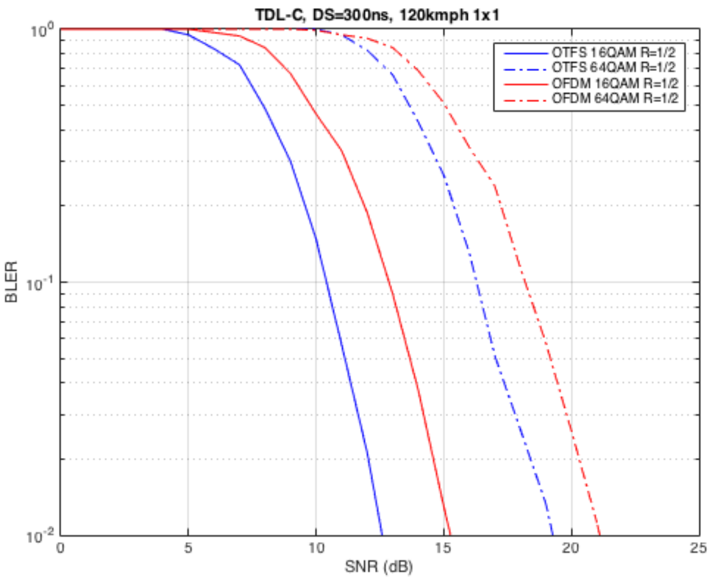

Figure 2: BLER performance for Case 1a, 1x1, 16QAM and 64QAM, R=1/2, 120kmph in TDL-C, DS=300ns channel

The performance for a small allocation is shown in Figure 3. This scenario is similar to Case 1b of [3] with some key differences. For OTFS the user is configured with 4 RBs in the Delay-Doppler domain. The QAM symbols are transformed to the time-frequency grid using a Discrete Symplectic Fourier transform, which spreads the data over the time-frequency grid. As such, OTFS natively supports frequency diversity in the time-frequency domain while enabling multiple access in the Delay-Doppler domain. Notice that for 16 QAM we see a gain of over 3.5 dB while for 64 QAM the gain is over 2 dB at an operating point of 1e-1. The significant performance advantage of OTFS over OFDM shown here is its ability to extract the full diversity of the channel independent of packet size since all QAM symbols experience the same time-frequency channel. In a separate contribution [4] we show multiuser performance when multiple UEs are multiplexed in the Delay-Doppler domain.

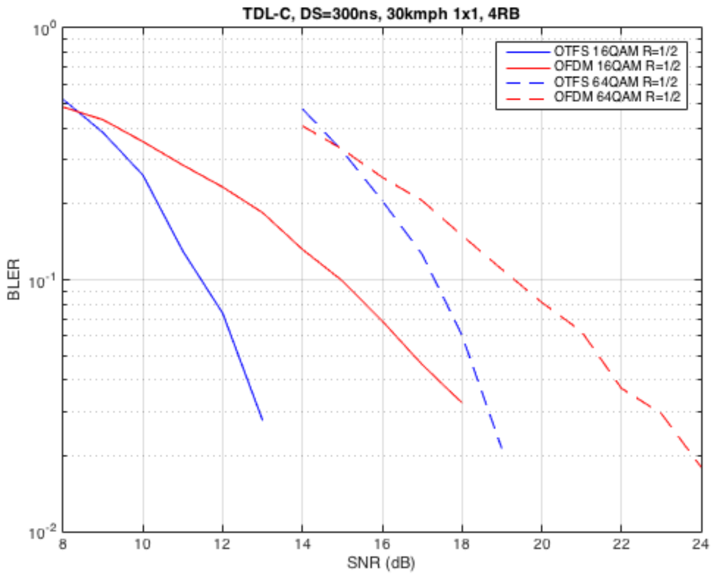

Figure 3: BLER performance for OFDM in Case 1b, OTFS 4RBs in D-D domain, 30kmph in TDL-C, DS=300ns channel

The next set of figures depict performance for multi-antenna systems. These results demonstrate MIMO performance in spatially uncorrelated channels, and serve as performance upper bounds for single user MIMO. Figure 4 and Figure 5 respectively show performance for a 2x2 system at 30 km/h and 120 km/h. It can be seen in Figure 4 that OTFS has a gain over OFDM of up to 2dB at the BLER operating point of 10^{-1}. Similarly, to the 1x1 scenario, the gain increases for higher speeds as shown in Figure 5. A gain of 2.5 dB and 4 dB is seen for 16 QAM and 64 QAM respectively for the same operating point.

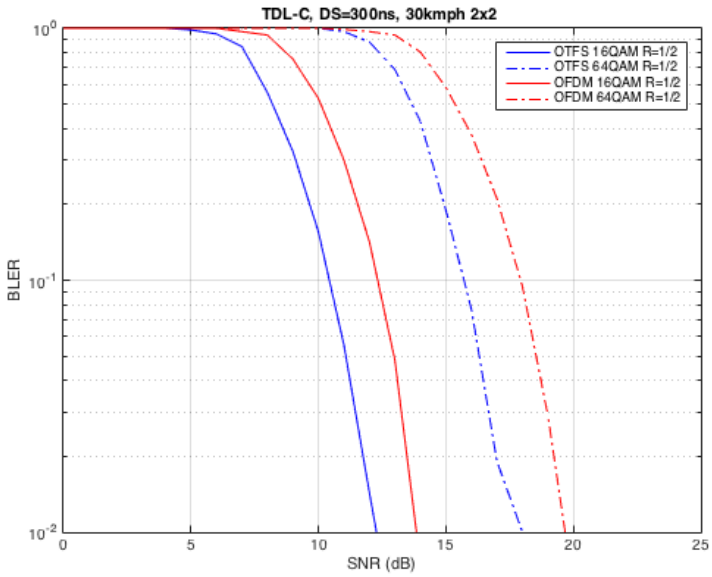

Figure 4: BLER performance for Case 1a, 2x2, 16QAM and 64QAM, R=1/2, 30kmph in TDL-C, DS=300ns channel

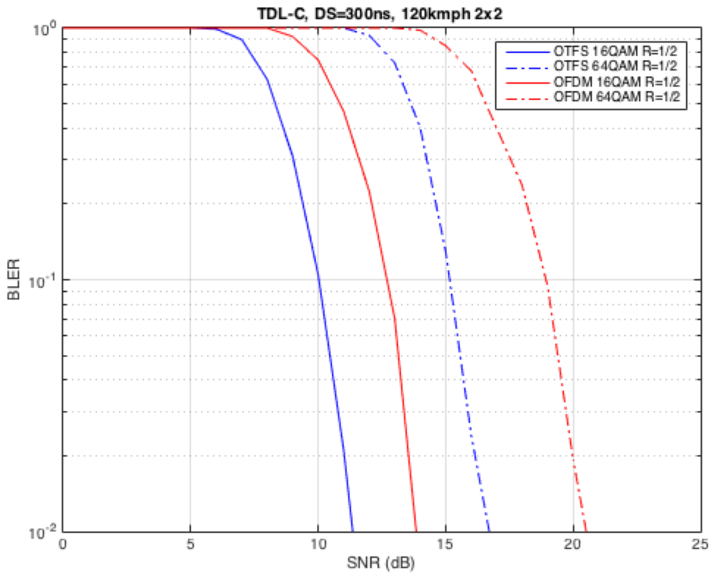

Figure 5: BLER performance for Case 1a, 2x2, 16QAM and 64QAM, R=1/2, 120kmph in TDL-C, DS=300ns channel

3. Conclusion

In this contribution, we compared the performance of OTFS to OFDM for a variety of single user deployment scenarios. We have shown that OTFS outperforms OFDM with increasing Doppler. Furthermore, the performance gain of OTFS increases over OFDM in MIMO scenarios. As a next step, we will evaluate performance in spatially correlated channels.

4. References

[1] R1-165620 "Performance Results for OTFS Modulation", Cohere Technologies

[2] R1-163619, "OTFS Waveform for New RAT", Cohere Technologies

[3] R1-163558 "Way forward on assumptions for waveform evaluation" Huawei, HiSilicon

[4] R1-167594, "Performance evaluation of OTFS waveform in multi user scenarios", Cohere Technologies

APPENDIX

Table 1 Simulation Parameters

Parameter	Value
Carrier frequency (GHz)	4.0
Duplex mode	FDD
Subcarrier spacing (KHz)	15
CP duration (us)	4.7
FFT Size	1024
Transmission Bandwidth (RBs)	50
Antenna configuration	1T1R, 2T2R, 4T4R
Rank	Fixed rank

MCS	Fixed: 16QAM rate ½, 64QAM rate ½
Control and pilot overhead	None
Channel estimation	Ideal
Channel model	TDL-C, DS = 300ns
UE speed (km/h)	30, 120
Receiver	OTFS: Turbo Equalizer, OFDM: Reduced ML