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R1-1609825

Source: Cohere Technologies

Title: OTFS Performance in High Doppler with Varying Subcarrier Spacing

Agenda item: 8.1.1.1

Document for: Discussion

1. Introduction

In the RAN1 86 meeting we presented performance comparisons of OFDM and OTFS (Orthogonal Time Frequency Space) for the high-speed use case where ICI is present [1]. These evaluations were based on the simulation assumptions of the way forward agreement of [2].

In this contribution, we present further results and evaluate the performance of OTFS and OFDM for different subcarrier spacing of 15 KHz, 30 KHz and 60 KHz in the presence of strong Doppler.

OTFS is a novel modulation technique presented in [3], [4], that is based of a 2-D FFT based preprocessing block on top of an OFDM multicarrier system resulting in improved performance, especially in the presence of high Doppler.

The results in the next section show that OTFS outperforms OFDM in all subcarrier spacing cases and is especially well suited for the high-mobility use case. OTFS allows operation without the need for increasing the subcarrier spacing with associated complexity and additional CP overhead.

2. Simulation Results

We evaluate the performance of OTFS versus OFDM using link level simulation and present comparison results. The Doppler spread in all simulations is 1820 Hz, corresponding to a UE speed of 500 Km/h at a carrier frequency of 4 GHz. A subcarrier spacing of 15, 30 and 60 KHz is used for both OTFS and OFDM systems. The channel delay profile used is Rural Macro and the MIMO correlation is low.

We start with ideal channel estimation and no control overhead in this comparison while we later present some results with realistic channel estimation. We use an ML receiver for OFDM and a turbo equalizer for OTFS. The turbo equalizer iterates between the decoder and a linear equalizer improving the performance in each iteration.

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, 30, 60 KHz
FFT size	1024
CP length	4.7 usec
Receivers	OTFS: Turbo equalizer, OFDM: ML

Coding	Turbo code, 6144 max code-block length
MCS	16-QAM ½, 64-QAM ½
Control overhead	No overhead
Channel estimation	Ideal, MMSE (part of turbo receiver)
Channel profile	Rural Macro TDL profile
UE Speed	500 Km/h
MIMO Correlation	Low

Figure 1 focuses on a SISO system and shows PER curves for OTFS vs OFDM for 16-QAM rate 1/2 in different line colors and for 15, 30 and 60 KHz subcarrier spacing in different line types. In order to focus exclusively on the ICI effects, in this figure ideal channel estimation is assumed for both systems. Notice that OTFS outperforms OFDM for every subcarrier spacing and further that increasing subcarrier spacing for OFDM only reduces the gap modestly.

We should also mention that in this simulation the CP length stays the same for every subcarrier spacing. This is turn implies higher overhead for higher subcarrier spacing which is not captured in this figure. In particular, the CP overhead is 7% for 15 KHz spacing, while it doubles and quadruples for 30 and 60 KHz respectively.

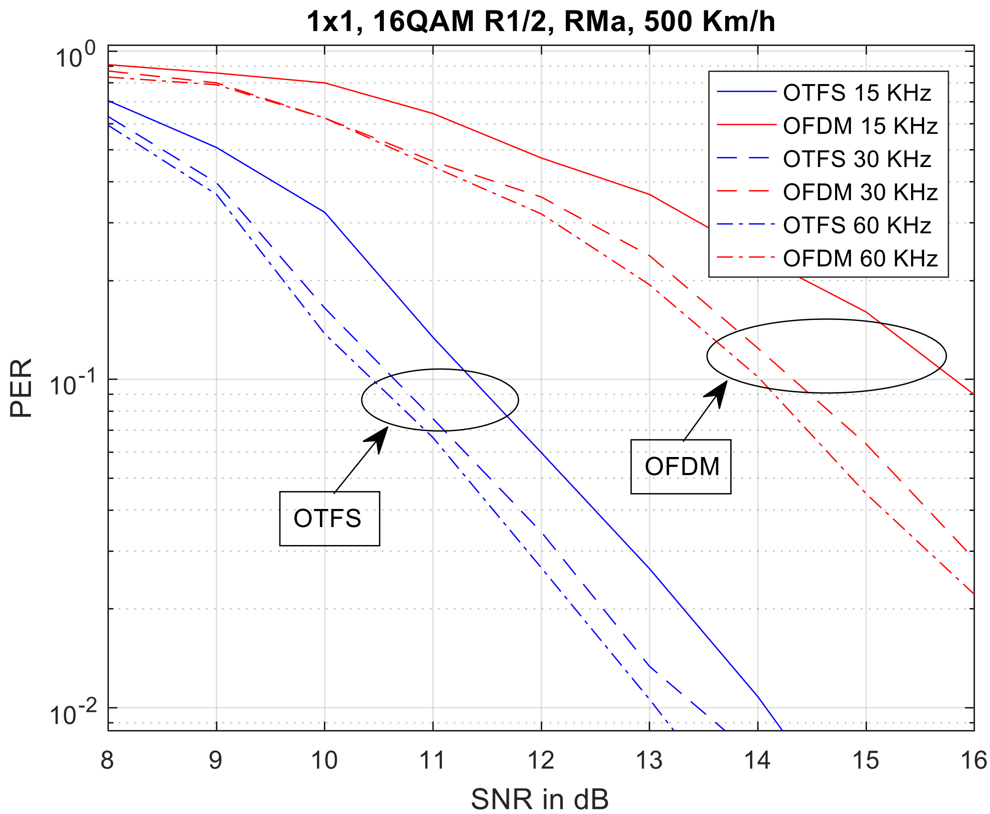

Figure 1: PER for 1x1 OTFS vs OFDM for varying subcarrier spacing.

In Figure 2 we present similar results for a 2x2 MIMO system. Similar, if not bigger performance gaps are observed in this case as well.

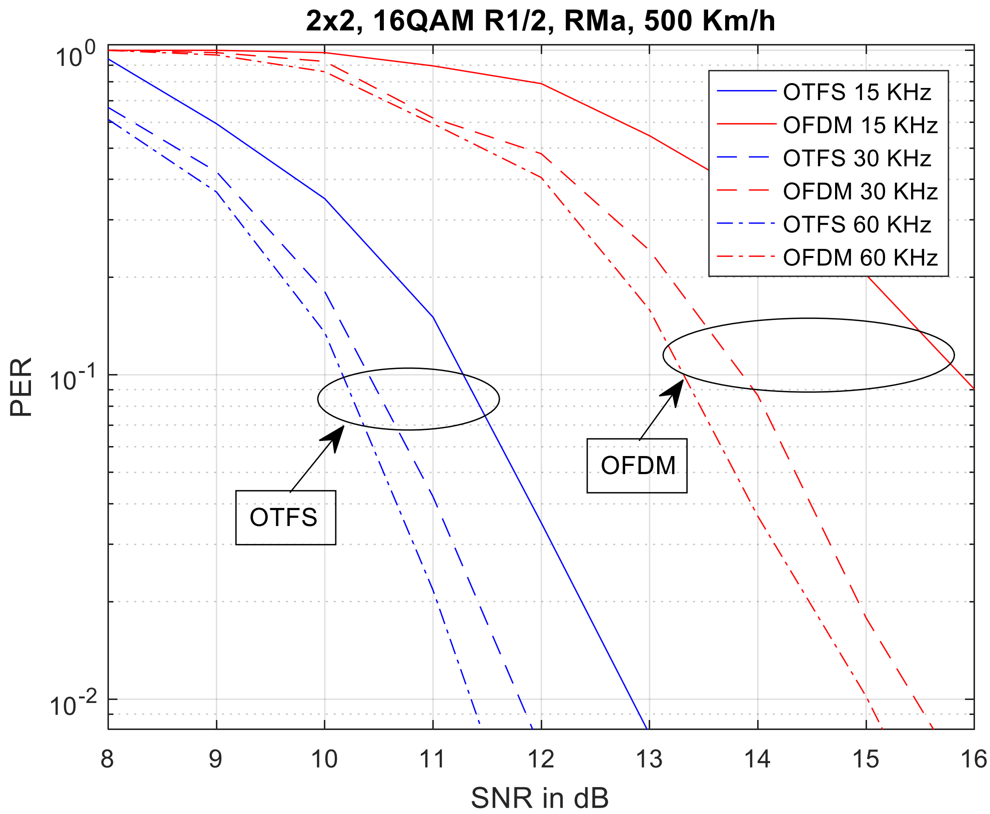

Figure 2: PER for 2x2 OTFS vs OFDM for varying subcarrier spacing.

The next two figures present similar results for 64 QAM rate ½ for 1x1 and 2x2 systems respectively. Notice that in this case both systems fail at 15 KHz spacing but at 30 KHz a significant performance difference develops. For example, in Figure 4 for the 2x2 case a performance difference of 6 dB can be seen.

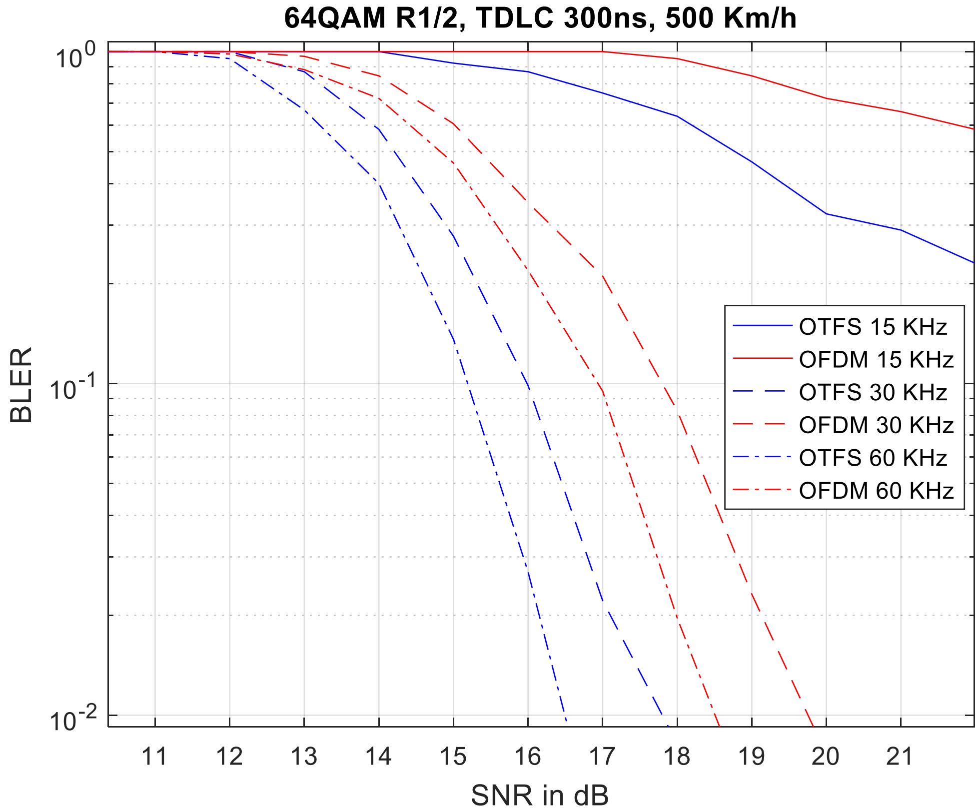

Figure 3: PER for 1x1 OTFS vs OFDM for varying subcarrier spacing

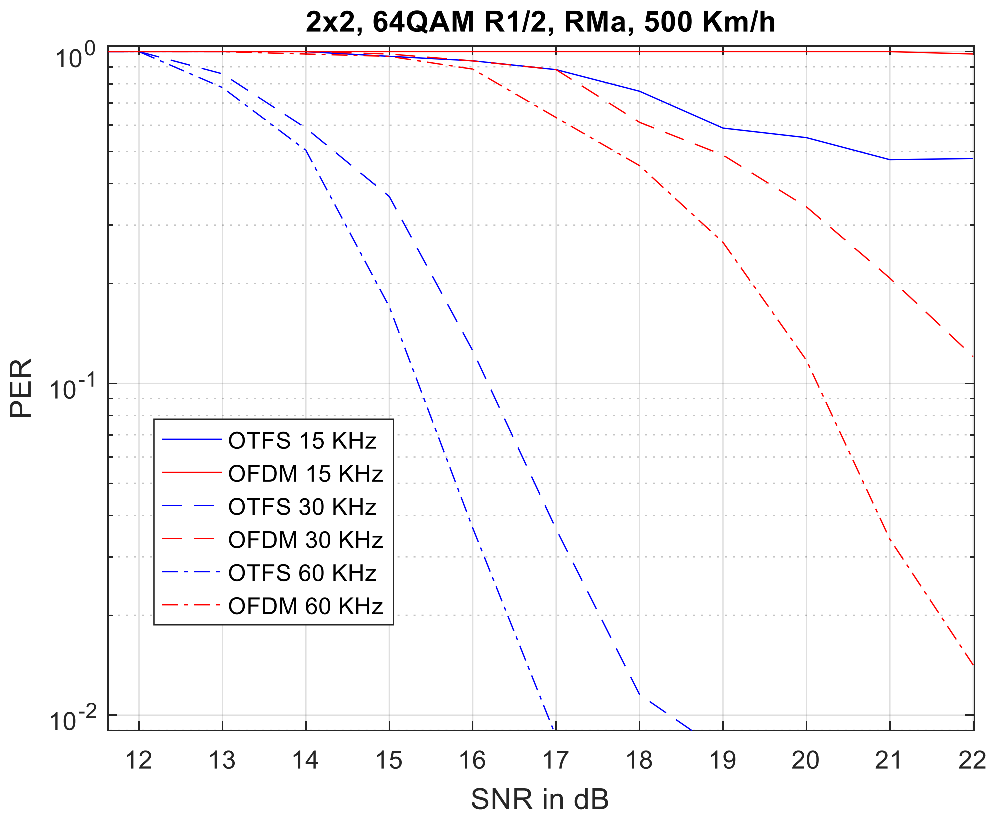

Figure 4: PER for 2x2 OTFS vs OFDM for varying subcarrier spacing

In the following table, we summarize the OTFS performance gains vs OFDM for a 10% PER operating point.

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

	1x1			2x2		
	15 KHz	30 KHz	60 KHz	15 KHz	30 KHZ	60 KHz
16 QAM R 1/2	4.2 dB	3.6 dB	3.5 dB	4.6 dB	3.5 dB	2.9 dB
64 QAM R 1/2	N/A	1.9 dB	1.9 dB	N/A	5.9 dB	4.6 dB

Next we investigate the performance difference when ICI cancellation in employed. In Figure 5, the performance of the two systems is compared assuming perfect ICI cancellation for both systems. As expected in this case, changing the subcarrier spacing does not affect the PER in a significant way.

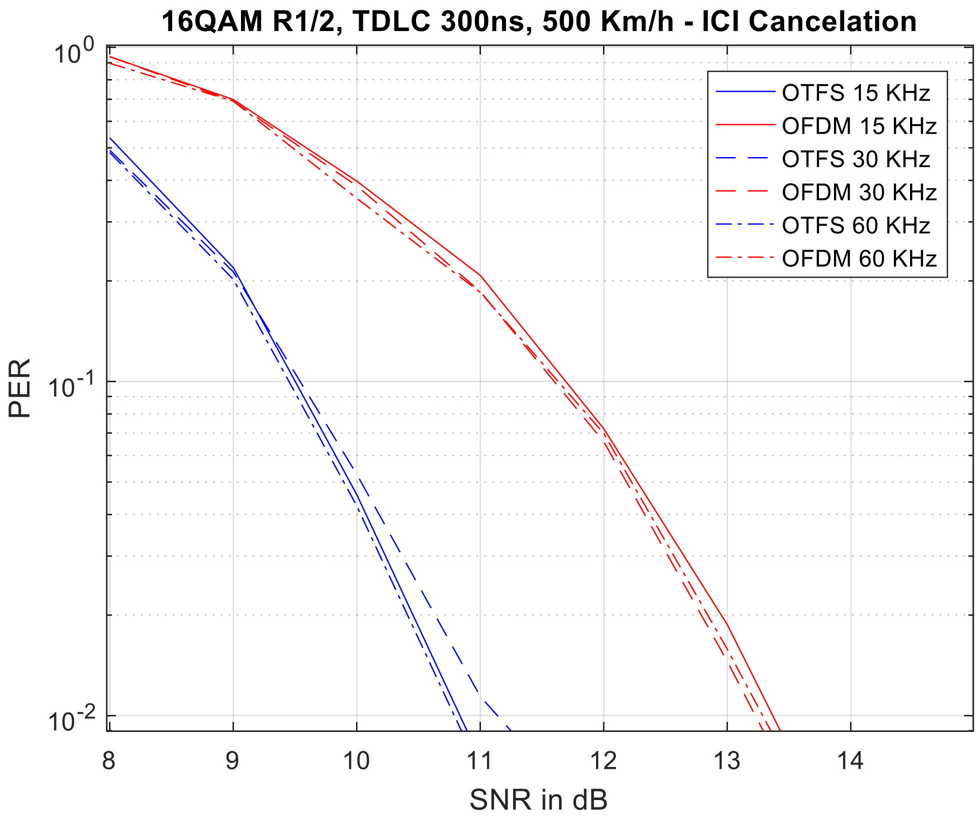

Figure 5: PER for 1x1 OTFS vs OFDM for varying subcarrier spacing

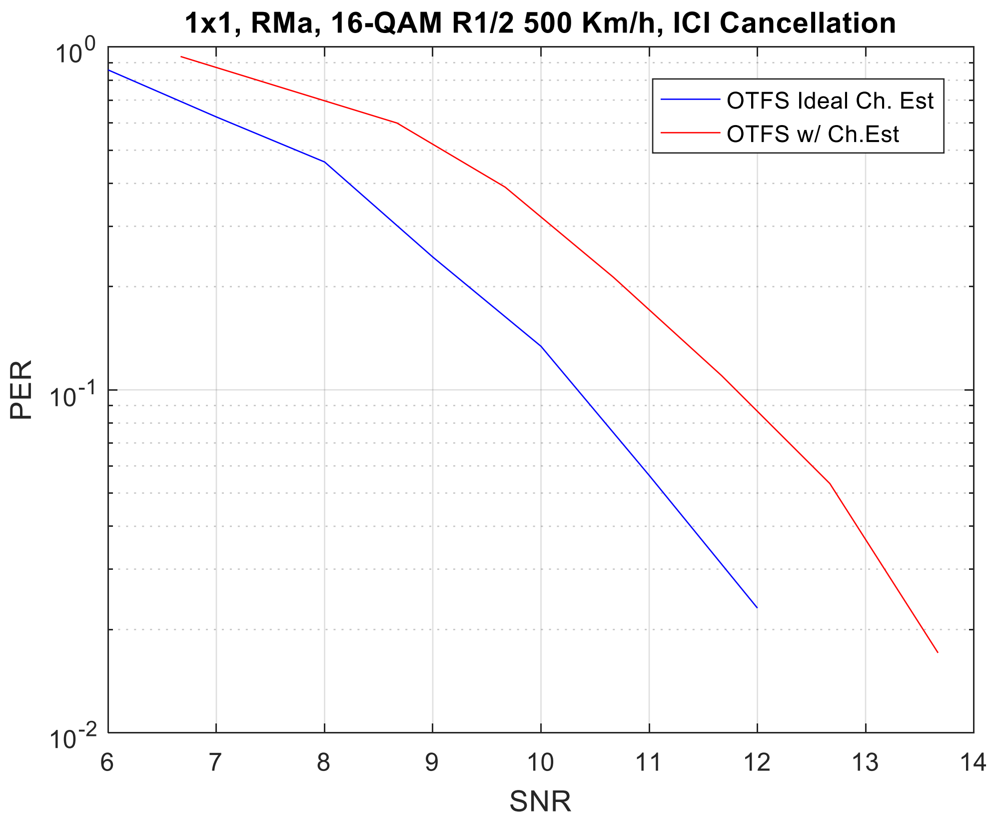

Figure 6: Comparison of ideal vs pilot based channel estimation

Finally, we present performance comparisons between ideal and realistic channel estimation. In Figure 6 we show the PER curves for an 1x1 OTFS system with ideal channel (blue line) as well as estimated channel (red line). Notice that a reasonable degradation of a bit more than 1 dB is observed.

A word of explanation is in order at this point to describe the approach taken for channel estimation. A pilot superposition scheme was used, that is, on the pilot grid points the data were not removed but remained superimposed with the pilots, i.e., each pilot grid point carried both pilot and data. The system used an iterative (turbo) receiver/equalizer with ICI cancellation. On the first iteration, the channel was estimated from the pilot grid considering the data as interference. In subsequent iterations, given some data priors, the data interference was removed from the pilot grid and a better channel estimate was obtained.

In these results a pilot grid of one every six subcarriers was used. Along time, the pilot grid was present in every OFDM symbol. This pilot overlay grid is depicted in

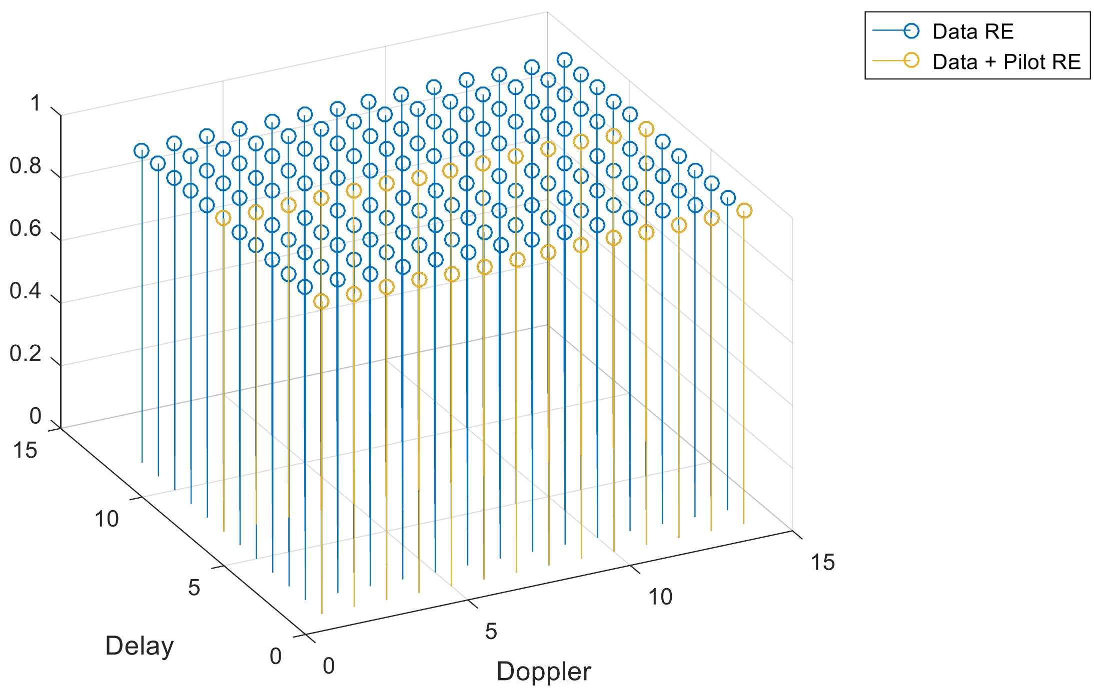

Figure 7. Notice that this pilot overlay scheme does not suffer from any bandwidth pilot overhead, i.e., the pilots consume zero degrees of freedom of the channel; the scheme only suffers a power overhead (in this case equal to 16%). Typical pilot placements often suffer both bandwidth and power overhead. This elimination of pilot bandwidth overhead is significant especially for higher order MIMO system that require considerable pilot resources.

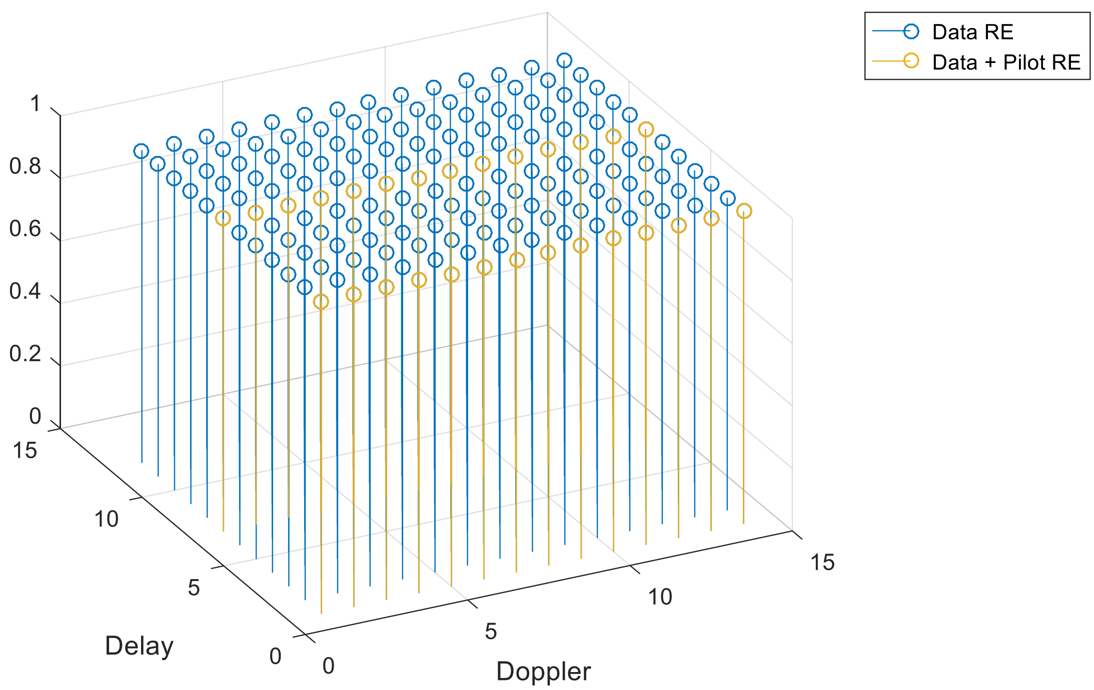

Figure 7: Data and pilot overlay on one PRB

3. Conclusion

The performance comparisons in this paper indicate the superior performance of OTFS for this high Doppler (high mobility) use case. Gains of up to 6 dB are seen in this extreme Doppler scenario. Further, the ability to operate without increasing the subcarrier spacing saves additional CP overhead associated with higher subcarrier spacing.

4. References

[1] R1-167595, “OTFS Performance Evaluation for High Speed Use Case”, Source: Cohere Technologies

[2] R1-166031, “Way forward on High Speed Link Level evaluation”, Source: Cohere, AT&T, CMCC, DT, InterDigital, National Taiwan University, Orange, Spreadtrum, Telefonica, Telstra

[3] R1-163619, “OTFS Modulation Waveform and Reference Signals for New RAT,” Source: Cohere Technologies

[4] R1-162929, “Overview of OTFS Waveform for Next Generation RAT,” Source: Cohere Technologies