

Design of Radar Waveforms and Channel Estimation in Delay Doppler Domain

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ABSTRACT

Sixth-generation wireless systems are expected to carry data and sense their surroundings with the same waveform, at speeds where the channel no longer holds still. Such channels are doubly selective: multipath spreads the signal in delay, and mobility spreads it in Doppler. Neither dominant physical-layer waveform copes well. Cyclic-prefix OFDM, which underpins 4G and 5G, assumes the channel is constant over a symbol duration; when it is not, sub-carrier orthogonality breaks down and inter-carrier interference (ICI) appears. Linear frequency modulated (LFM) chirps, the standard radar probe, have a self-ambiguity function supported on a continuous band, so in a dense scene the bands of distinct reflectors intersect and produce “ghost targets”. This thesis addresses both problems in the delay-Doppler (DD) domain, using the Zak transform and Zak-OTFS modulation.

The first contribution is a radar waveform for the identification of linear time-varying (LTV) systems. We show that the self-ambiguity function of the Zak-OTFS pulsed waveform is supported on a two-dimensional discrete lattice rather than a continuous band. In the crystalline regime, where the delay and Doppler periods exceed the corresponding channel spreads, lattice peaks belonging to distinct targets cannot overlap, and ghost targets are eliminated even for fractional delay and Doppler shifts. The accompanying cross-ambiguity estimator runs in $\mathcal{O}(BT \log BT)$ against $\mathcal{O}((BT)^2)$ for chirp-based processing, and resolves $\mathcal{O}(BT)$ targets. Simulations show lower RMS range and velocity error than both LFM chirps and MC-OTFS.

The second contribution carries the same crystallisation property into legacy CP-OFDM without altering the RF chain. A Zadoff-Chu pilot designed in the DD domain is precoded to the frequency domain by an Inverse Discrete Frequency Zak Transform and superimposed on the payload, so no demodulation reference signals are needed. At the receiver, a Discrete Frequency Zak Transform post-processor recovers the effective DD channel filter from a single OFDM block. We derive the mapping from this filter to the complete frequency-domain input-output relation, including the ICI coefficients that per-sub-carrier estimation cannot reach, and use it to equalise all sub-carriers jointly under an MMSE criterion. On the 3GPP TDL-C channel the scheme exceeds the DMRS-based baseline in spectral efficiency at $\nu_{\max} = 1000$ Hz and continues to operate at 2000 and 3000 Hz, where the baseline supports no 5G NR modulation-and-coding scheme at a block error rate of 0.1.

Together these results show that delay-Doppler processing supports both high-resolution sensing and reliable communication under extreme mobility, and that the latter can be retrofitted to deployed hardware.