Abstract of Ph.D. Thesis
"Delay-Doppler Domain Pulse Shaping for Reliable Communication in High Delay and Doppler Spread Wireless Channels"

Mr. Jinu Jayachandran (2017EEZ8174)

Reliable wireless communication under high-mobility conditions, characterized by large delay and Doppler spreads, presents substantial challenges to conventional modulation schemes. Orthogonal Frequency Division Multiplexing (OFDM), though widely adopted, suffers severe performance degradation in such doubly dispersive channels due to loss of orthogonality and increased inter-symbol interference. To address these limitations, delay-Doppler (DD) domain modulation—specifically Zak-transform-based Orthogonal Time Frequency Space (Zak-OTFS) modulation—has emerged as a promising framework. Zak-OTFS operates natively in the DD domain and provides a quasi-periodic, crystalline input-output relation that improves robustness and predictability even under extreme channel conditions.

The first major contribution of this thesis is the design and analysis of a delay-Doppler domain Gaussian pulse shaping filter for Zak-OTFS systems. Unlike conventional rectangular or sinc pulses, the proposed Gaussian pulse achieves improved joint time-frequency localization, which enhances DD domain predictability and minimizes aliasing. Analytical expressions for the time-domain (TD), frequency-domain (FD), and effective DD domain channel response are derived. Simulation results demonstrate that Gaussian pulses offer superior Bit Error Rate (BER) performance and reduced time-bandwidth expansion compared to Root Raised Cosine (RRC) and sinc-based filters.

The second contribution focuses on joint sensing and communication (JSAC) using a turbo signal processing algorithm. A novel iterative framework is proposed to jointly refine channel estimation and data detection within Zak-OTFS transmissions that employ spread pilots. The proposed turbo algorithm exploits the quasi-periodic structure of Zak-OTFS and exchanges soft information between the sensing and communication modules. Numerical evaluations show that the BER performance using the turbo algorithm approaches that of perfect Channel State Information (CSI), particularly when using Gaussian pulse shaping filters.

The third contribution addresses the limitation of fixed Doppler support in Zak-OTFS systems through the development of an interleaved pilot-based transmission strategy. In scenarios where the actual Doppler spread exceeds the preconfigured Zak period, conventional pilot arrangements fail to maintain predictability. To overcome this, multiple interleaved pilots are introduced to effectively extend the Doppler support without altering the fundamental delay or Doppler periods. Analytical models for

the auto-ambiguity function and crystallization condition are derived, and simulations confirm that the method significantly enhances the region of reliable operation and improves BER performance, especially at high Doppler spreads.

Overall, this thesis advances the theoretical foundations and practical implementations of Zak-OTFS modulation by proposing innovative solutions in pulse shaping, iterative detection, and adaptive pilot placement. These developments contribute toward establishing Zak-OTFS as a viable candidate for next-generation 6G wireless systems that demand reliable, high-mobility communication and integrated sensing capabilities.