Abstract

This thesis investigates advanced channel estimation techniques for terahertz (THz) ultra-massive multiple-input multiple-output (UM-MIMO) systems, a cornerstone technology for sixth-generation (6G) wireless communications. THz UM-MIMO promises terabit-per-second data rates and ultra-low latency but faces severe challenges, including extreme path loss, molecular absorption, dual wideband effects (beam squint and delay squint), spatial non-stationarity (SNS), frequent line-of-sight (LoS) blockages, and near-field spherical wavefront propagation.

To address these challenges, the thesis proposes a family of innovative, scalable channel estimation frameworks that progressively overcome the limitations of conventional methods: First, an on-grid sparse Bayesian learning (OBL) channel estimator for far-field THz UM-MIMO systems and an extended Kalman filter (EKF)-based angle tracking for doubly selective channels are developed under dual wideband effects. Second, a gridless iterative wideband atomic norm minimization (GI-WANM) channel estimator is proposed that eliminates the grid-mismatch errors inherent in on-grid channel estimators and jointly addresses dual wideband effects, SNS, and LoS blockages in far-field THz UM-MIMO systems. Third, the full-dimensional (FD) gridless joint wideband atomic norm minimization (JWANM) near-field channel estimator is introduced, specifically designed for THz UM-MIMO systems employing uniform planar arrays at the base station and user, accurately capturing spherical wavefronts, frequency-dependent steering vectors, SNS-induced visibility regions, and molecular absorption effects and avoiding the grid-mismatch problem. Additionally, the feasibility of extending the proposed JWANM framework to uniform circular array-assisted FD near-field THz UM-MIMO systems is discussed, along with the associated practical challenges.

Extensive simulation results demonstrate that the proposed channel estimators significantly outperform state-of-the-art benchmarks, including least squares (LS), orthogonal matching pursuit (OMP), generalized simultaneous OMP (GSOMP), off-grid sparse Bayesian learning (SBL), polar domain simultaneous OMP (P-SOMP), polar domain simultaneous iterative gridless weighted (P-SIGW), and two-stage hybrid message passing (HMP), in terms of normalized mean squared error (NMSE) and bit error rate (BER) across different conditions. The gridless approaches exhibit exceptional robustness to grid-mismatch, dual wideband, and SNS effects, while approaching the Cramér-Rao lower bound in near-field regimes. These contributions provide robust, accurate, and practical channel estimation solutions for real-world THz UM-MIMO

deployments, paving the way for reliable terabit wireless communications in future 6G wireless communications.

Keywords: 6G, Terahertz Communications, Ultra-Massive MIMO, Near-Field, Dual Wideband Effects, Spatial Non-Stationarity, LoS Blockage, Channel Estimation, Hybrid Beamforming/Combining.