FOR 2863 Meteracom
Metrology for
THz Communications

A2: Experimental Performance Validation of Fisher Information-Optimized Multicarrier Waveforms for Sub-THz Channel Sounding

Jonas Gedschold, Sebastian Semper, Alexander Ebert, Giovanni Del Galdo, Reiner S. Thomä

Technische Universität Ilmenau

I – Introduction

- **Goal** of channel sounding: Measure and characterize the wireless channel.
- **Tool**: Model-based parameter estimation to derive delays of propagation paths in a multipath scenario.
- **Observation**: The design of the sounding waveform directly influences the performance of the parameter estimator.
- **Motivation**: Sub-THz channel sounding is challenged by a **low** achievable **SNR** (high isotropic path loss, limited capabilities of THz amplifiers).
- This impacts the performance of the parameter estimation, leading to a higher estimation variance.
- **Objective**: Implement and verify a waveform design procedure that minimizes the achievable estimation variance given a certain transmit power.
- **Result**: Use available transmit power in an optimal sense.

II – Signal Model

- A multicarrier signal is used as a blueprint, and the design objectives are the power and phase spectra assigned to the carriers.
- Signal model for the receive carrier weights y:

$$y_i = c_i \cdot \sum_{k=1}^{K} \gamma_k \cdot \exp(-j2\pi f_i \tau_k) + n_i$$

- c_i: transmitted carrier weights (design goal)
- K: number of propagation paths
- i: carrier index
- γ: path weight, τ: propagation delay
- n: additive white Gaussian noise

III – Waveform Optimization

- The optimization of the carrier weights c is based on the Fisher information matrix **F** and minimizes the Cramér-Rao lower bound

$$|c_i|^2_{(n+1)} = |c_i|^2_{(n)} \cdot \text{trace}\left(\mathbf{F}^{-1} \cdot \frac{\mathbf{F}_i}{|c_i|^2}\right)$$

- $\mathbf{F}_i$: Fisher information for a single carrier with index i
- The calculation of **F** depends on the derivatives of the signal model, hence, requires a prior knowledge about the model parameters
- **Proposed two-step processing flow**:

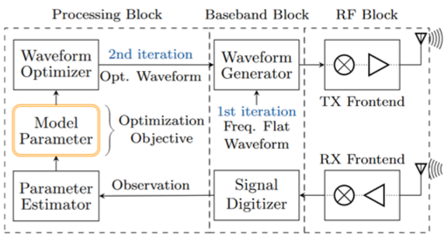

Fig. 1: Proposed processing flow chart for the presented waveform optimization routine.

IV – Measurement Setup

- The following hardware implements the setup from Fig. 1:
- R&S®SMW200A for waveform generation
- R&S®FE170ST/SR for up/down-conversion to 160 GHz with 2 GHz of bandwidth attached to horn antennas (Fig. 2)
- R&S®FSW signal and spectrum analyzer for recording of baseband IQ samples
- An **artificial test channel** is created using two metal rods as scatterers in front of a bistatic transmitter/receiver constellation

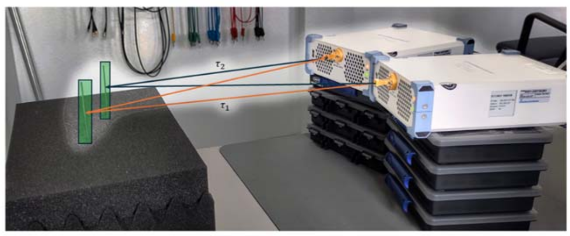

Fig. 2: Measurement setup showing the targets (green) and the two propagation paths (blue, orange).

V – Signal Processing

- An initial parameter estimation is required for an initial guess about the channel (compare Fig. 1)
- To evaluate the impact of the accuracy of this initial guess, two intermediate parameter estimators are compared:
  - **fast**: Interpolated grid search (FFT) using 100 signal periods.
  - **fine**: Gradient-refined Maximum Likelihood estimation using 10 k signal periods (RiMAX)
- The **empirical variance** is evaluated as a post-processing step on the recorded data acquired with the optimized waveform using the "fine" method (compare Fig. 3)

VI – Results

- Path difference was 21 cm (slightly above the Rayleigh resolution)
- For low transmit powers, the MSE saturates since the paths cannot be detected reliably
- The improvement with the optimized waveform compared to a frequency-flat one is most significant for **mid-range SNR** regions

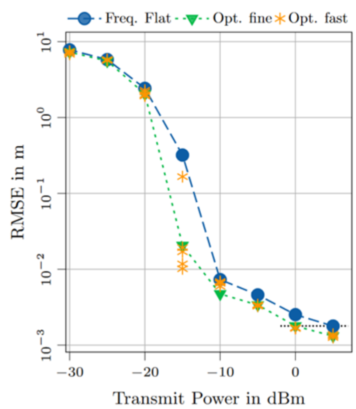

Fig. 3: Comparison of the empirical MSE for the different waveforms.