Time and Frequency Synchronization for OTFS

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Abstract and Introduction

- Orthogonal frequency division multiplexing (OFDM) modulation has been playing a key role in the 4th and 5th generations of the wireless network.
- One of the main challenges faced by the 6th generation wireless networks (6G) is to provide reliable communication to high-mobility users.
- High mobility makes the channel doubly dispersive that can be modeled by a linear time-varying (LTV) channel.
- Orthogonal time frequency space (OTFS) modulation has become a strong candidate waveform for the 6G.
- OTFS interesting properties include resilience to the time-varying channel effects and backward compatibility with the previous-generation wireless system, [1].
- Synchronization is a challenge in the design of any practical communication system, especially when the channel is time-varying.
- There is no work on joint timing offset (TO) and carrier frequency offset (CFO) estimation for OTFS, [2-4].
- By estimating the offsets, users can pre-compensate the TO and CFO before the uplink transmission.
- We propose timing offset (TO) and carrier frequency offset (CFO) estimators for OTFS.

OTFS Principle

- Although OTFS has many attractive properties, it is very sensitive to synchronization errors, [2].
- OTFS signal is the combination of M up-sampled and delayed OFDM signals, each with N Doppler domain subcarriers, [5].

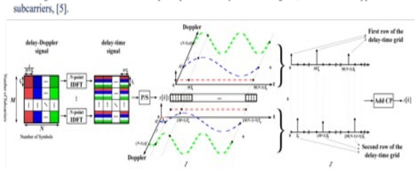


Fig. 1: OTFS as an OFDM.

- The received signal of B OTFS blocks can be formulated as:

$$r[k] = e^{\frac{j2\pi\varepsilon k}{MN}} \sum_{i=0}^{B-1} \sum_{\ell=0}^{L-1} h[\ell,k]\, s[k-\ell-\theta-iN_{\mathrm{T}}] + \eta[k]$$

Carrier Frequency Offset; Channel (length L); Timing Offset; Additive Noise

Pilot

- The isolated pilot for channel estimation, [6]:

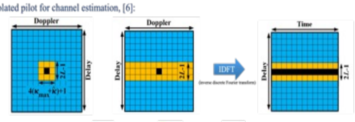


Fig. 2: Two isolated pilot patterns in the delay-Doppler and delay-time domains.

- Inserting the isolated pilot at (m_p, n_p) position in the delay-Doppler domain.
- Taking the isolated pilot from delay-Doppler to the delay-time domain leads to a constant amplitude sequence on the row m_p of the delay-time grid with a linear phase.
- The isolated pilot in the delay-Doppler domain that is utilized for channel estimation has periodic properties in the delay-time domain.
- The delay-time domain pilot signal has a periodic structure on a given delay bin, i.e., a row on the delay-time grid where the pilot is located. Hence, the start of each OTFS block can be found by searching for this periodic pilot signal on the delay-time grid.

Proposed Timing and Carrier Frequency Offset Estimation Techniques

- 2D received signal:

Delay Index, Time Index

$$r[m,l] = r[Ml+m]$$

- Defining a 2-D Correlation Function for Synchronization in OTFS, [7]:

$$P[m,l] = \sum_{q=0}^{N-2} r^{*}[m,l+q]\, r[m,l+q+1]$$

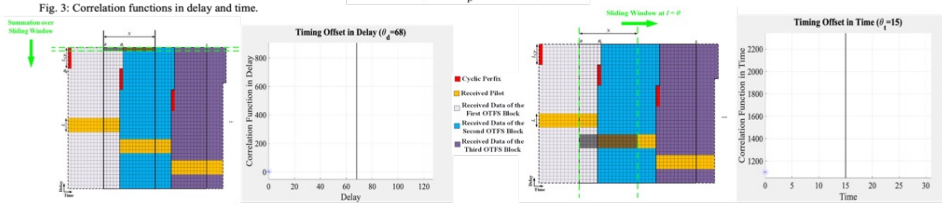
- Based on the 2D structure of the OTFS block in the delay-time domain, we decompose the TO as,

$$\theta = \theta_{\mathrm{d}} + M\theta_{\mathrm{t}}$$

- CFO estimation by finding the mean of the angles of a 2D correlation function at the best timing instant:

$$\hat{\varepsilon} = \frac{N}{2\pi L}\left(\sum_{m=m'_{\mathrm{p}}}^{m'_{\mathrm{p}}+L-1} \angle P[m,\hat{\theta}_{\mathrm{t}}]\right) - n_{\mathrm{p}}$$

Fig. 3: Correlation functions in delay and time.



Simulation Results

- Analyze the performance of our proposed TO and CFO estimation techniques through simulations.
- In our simulations, we study the mean and variance of the TO estimation error and the mean square error (MSE) of the CFO estimates.
- We also analyze the bit error rate (BER) performance of our proposed synchronization techniques.
- BER performance of the proposed synchronization techniques lead to the same performance as a fully synchronous system even when the channel is highly time-varying.

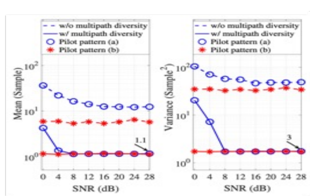


Fig. 4: Mean and variance of the proposed TO estimator for M=128 and N=32 and $\nu_{\max}T \approx 1.46$.

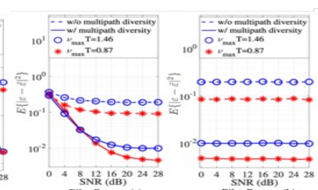


Fig. 5: MSE performance of the proposed CFO estimation technique for M=128 and 32.

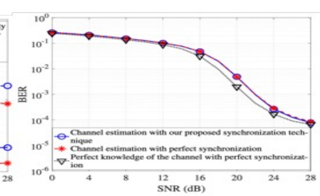


Fig. 6: BER of the proposed technique for M=128, N=32, and $\nu_{\max}T \approx 1.46$.

Conclusion

- TO and CFO estimation techniques for OTFS are proposed in this presentation.
- Timing offset estimation without any acquisition range limitation.
- Carrier frequency offset estimation without any acquisition range limitation.
- The proposed techniques do not require any additional training overhead (same pilot that is utilized for channel estimation, is also deployed for synchronization).
- TO estimator forms a 2D correlation function and finds the start of each OTFS block by searching for a periodic sequence of the pilot in delay and time dimensions.
- A small TO estimation error in delay can be tolerated by using a slightly longer CP.
- A single estimation error in time leads to total misalignment of the received OTFS block.
- The TO and CFO estimation accuracy is improved by exploiting the multipath diversity of the channel.
- Exploiting the multipath effect of the channel improves the CFO estimation accuracy in the order of 10.
- We assessed the BER performance of our synchronization techniques and showed that our proposed estimators can provide the same BER performance as that of a fully synchronous system.
- TO estimation technique is a biased estimator that the bias originated from the mean of delay in the EVA channel model.

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Acknowledgement and Contact

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SFI Frontiers for the Future Project, NEW WAVE

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