Practical Implementation of Zak-OTFS at WINLABS

Towards 6G waveform design

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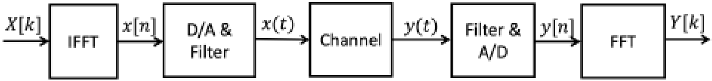

- Information symbols are multiplexed in the frequency domain

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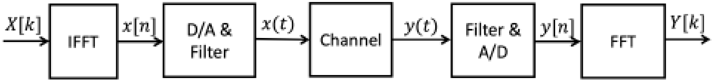
OFDM



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- 1-D transform in the frequency domain (IFFT/FFT)

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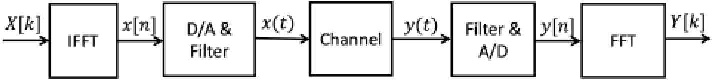

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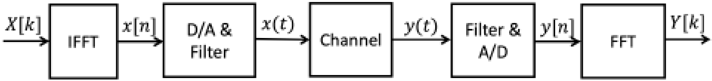

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- Orthogonality among the sub-carriers is the key
- High Doppler channels causes ICI

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OTFS

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- Performs good in doubly dispersive channels

Channel representation

LTV multipath channels can be represented as a function of

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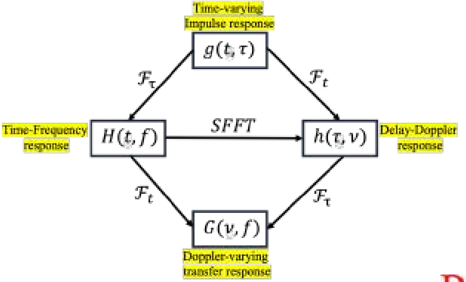

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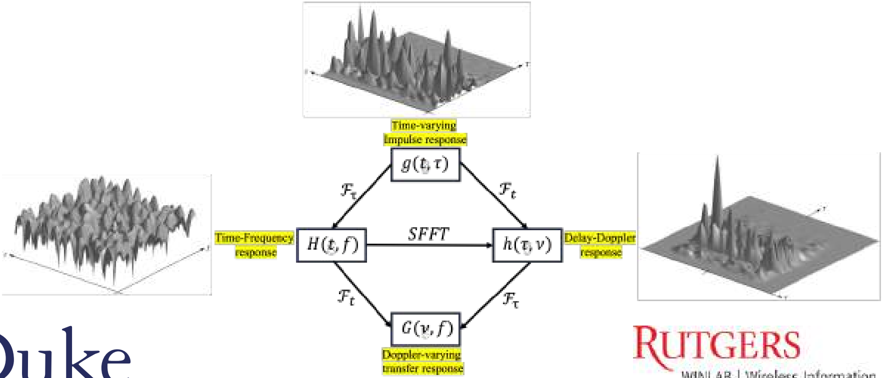

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OTFS Key features

- The channel response in the DD domain is invariant for a larger observation time

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- The channel response in the DD domain is invariant for a larger observation time
- Each symbol experiences nearly constant channel gain
- Channel interaction with transmit symbols is 2-D convolution rather than multiplication

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Zak-OTFS/OTFS 2.0

- One-step conversion from DD to time and time to DD domains

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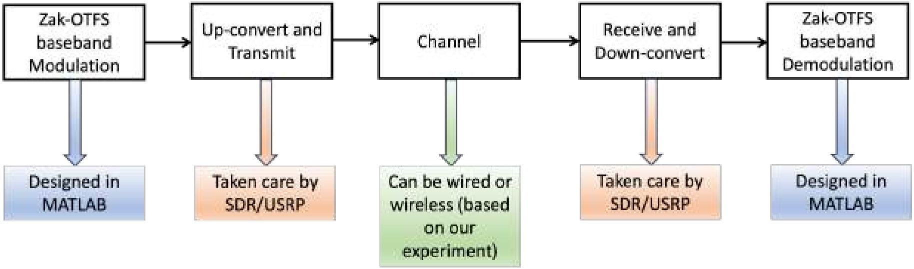
- One-step conversion from DD to time and time to DD domains
- More robust to large channel spreads compared to OTFS 1.0
- When operating in a crystalline regime, the predictability of the I/O relation is simple.

Design Flow



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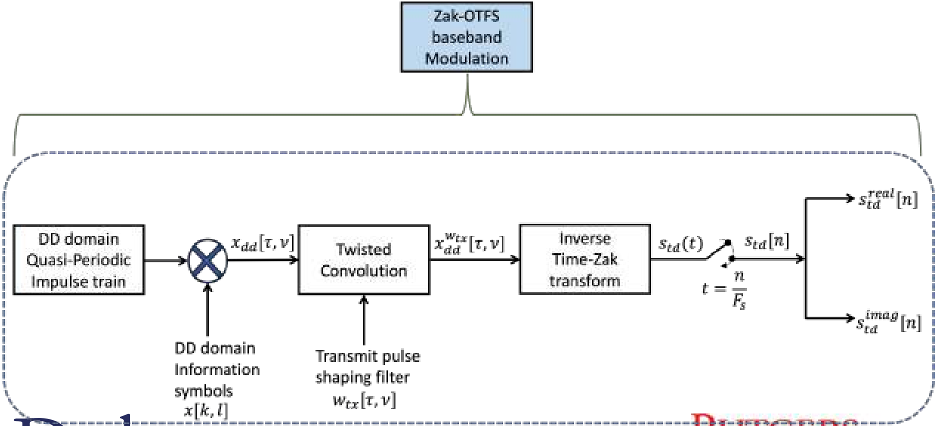
Zak-OTFS baseband modulation

The information symbols $a[0], a[1], \cdots, a[MN-1]$ are multiplexed in DD domain such that $x[k,l] = a[k+Ml]$, where $k = 0, 1, \cdots, M-1$ and $l = 0, 1, \cdots, N-1$.



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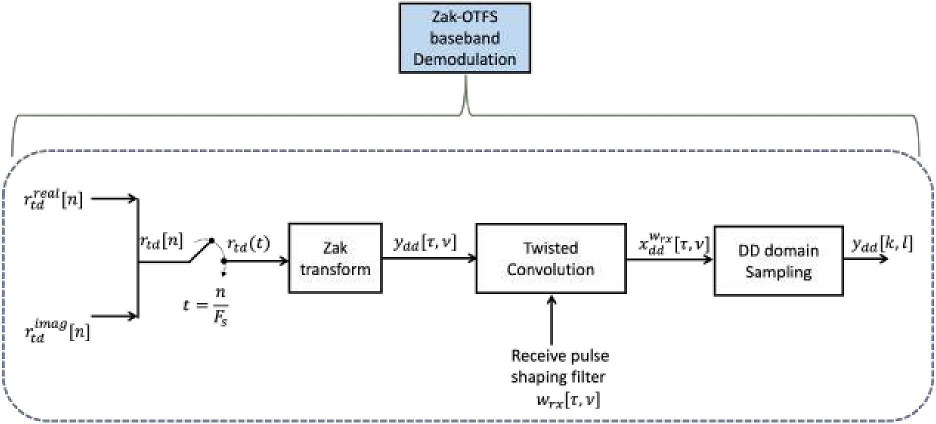
Zak-OTFS baseband de-modulation



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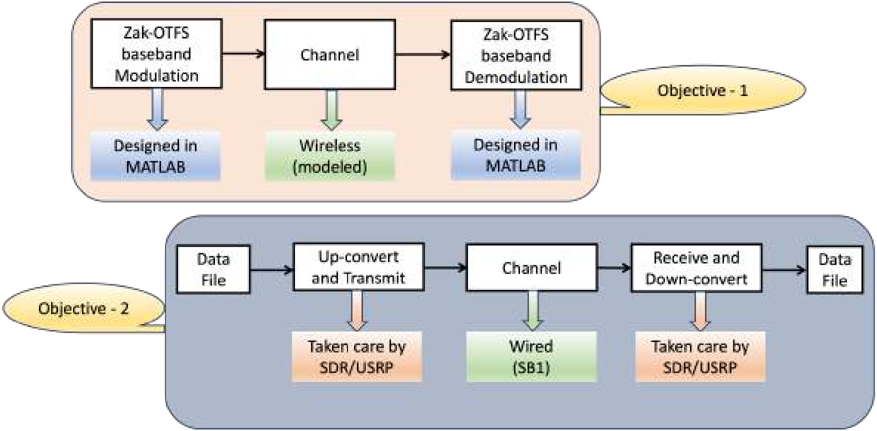
Implementation



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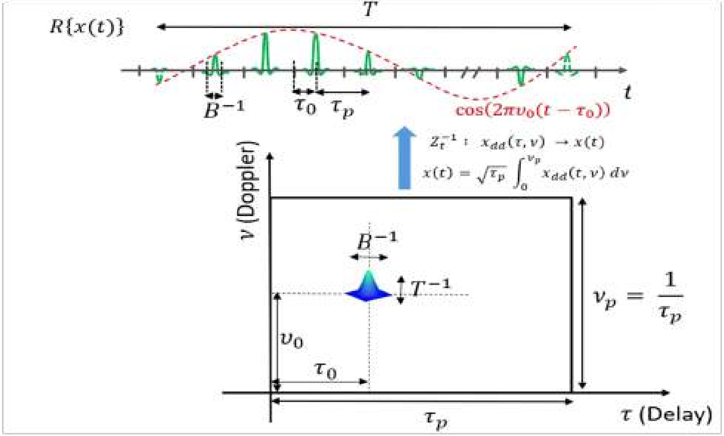
Zak-OTFS Transmit signal with Point Data (Theory)



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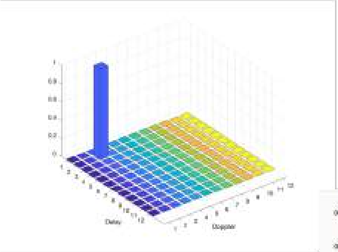
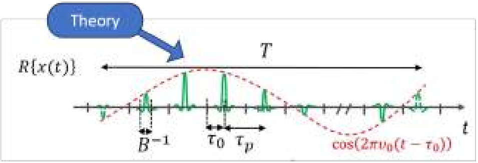
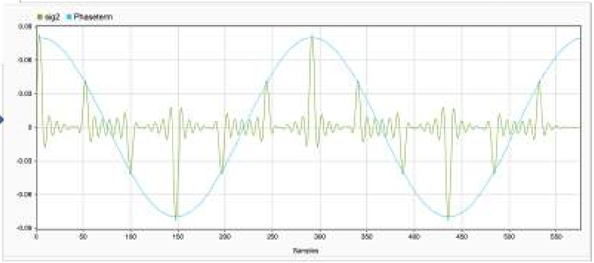
Zak-OTFS Transmit signal with Point Data (Practical)



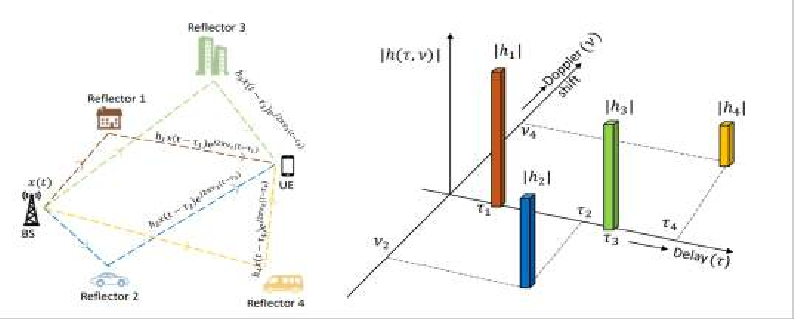


Practical



DD spreading function

- DD spreading function, $h(\tau, \nu) = \sum_{i=1}^{p} h_i \delta(\tau - \tau_i)\delta(\nu - \nu_i)$
- Received signal, $y(t) = \sum_{i=1}^{p} h_i x(t - \tau_i) e^{j2\pi\nu_i(t-\tau_i)}$



MATLAB Experiment with DD spreading function

DD Spreading Function

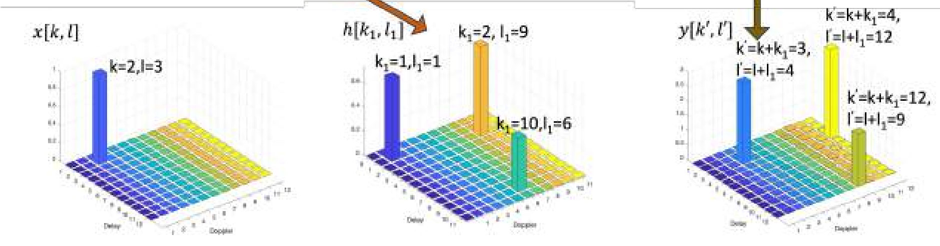
$$h(\tau,\nu) = \sum_{i=1}^{P} h_i\, \delta(\tau - \tau_i)\delta(\nu - \nu_i)$$

at $\tau = \frac{k\tau_p}{M}, \nu = \frac{l\nu_p}{N}$

DD Received signal

$$y[k',l'] = \sum_{k,l\in\mathbb{Z}} h_{dd}[k'-k, l'-l]\, x[k,l]\, e^{\frac{j2\pi(l'-l)k}{MN}}$$

where $h_{dd}[k,l] = w_{rx}[k,l] *_{\sigma} h[k,l] *_{\sigma} w_{tx}[k,l]$



DD input signal | DD channel | DD Received signal

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Project Goals

Stage-1 of Implementation

We use MATLAB to generate Zak-OTFS transmit samples and transmit them using SB1 (ORBIT), where the medium of transmission is a wire. The received samples are processed again in MATLAB.

Stage-2 of Implementation

Signal Processing is same as that of Stage-1, but the medium of transmission is wireless. We use MIMO facility in WINLABS to perform this experiment.

Stage-3 of Implementation

Signal Processing and channel is same as that of Stage-1. But we use SB4 (ORBIT), where the medium of transmission is a wire with a programmable attenuator. Using the results at this stage, we will produce an SNR versus BER curve.

Stage-4 of Implementation

Signal Processing and channel is same as that of Stage-1. But we use Grid (ORBIT) or MIMO facilities, where the medium of transmission is wireless but the transmit and receive antennas are very far apart.

Stage-5 of Implementation

We need to convert MATLAB code to C/C++ or some code that is compatible with GNU Radio, where there is a lot of scope to add additional blocks so as to design Zak-OTFS-based real-time transmission and reception.

Stage-6 of Implementation

We will be transmitting and receiving the signal over mm-wave frequencies.

Note: For these 5 stages of implementation, we will be using sub-6 GHz frequencies (around 2.4 GHz) to transmit and receive signals.

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THANK YOU

QUESTIONS & SUGGESTIONS

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