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Low Complexity Iterative Rake Decision Feedback Equalizer for Zero-Padded OTFS Systems

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ABSTRACT: Orthogonal time frequency space (OTFS) modulation scheme has been recently proposed and finds useful in several applications. In this paper an insight is made into a linear complexity iterative rake detector. In this scheme the basic idea is to extract and coherently combine the received multipath components of the transmitted symbols in the delay-Doppler grid using maximal ratio combining (MRC) to improve the SNR of the combined signal. In a simple vector form, OTFS input-output relation can be represented by placing guard null symbols or zero padding (ZP) in the delay-Doppler grid and exploiting the resulting circulant property of the blocks of the channel matrix. Using this vector input-output relation a low complexity iterative decision feedback equalizer (DFE) based on MRC can be developed. This detector has performance and complexity similar to the state of the art message passing detector. An alternative time domain MRC based detector can be developed for even faster detection. The MRC detector can be combined with outer error-correcting codes to operate as a turbo DFE scheme to further improve the error performance.

KEYWORDS: Orthogonal time frequency and space, delay-Doppler domain, OFDM, D-OSDM.

I. INTRODUCTION

Orthogonal time frequency and space (OTFS) is a new two-dimensional (2D) modulation technique that transforms information symbols in the delay-Doppler domain to the familiar time-frequency domain by spreading all the information symbols (e.g., QAM) over both time and frequency to achieve maximum effective diversity. As a result, a time-frequency selective channel due to multipath fading and mobility is converted into a separable and quasi-orthogonal interaction, where all received information symbols experience roughly the same localized impairment. Hence, for each information symbol, the received components in all the delay Doppler diversity branches can be separated and coherently combined.

OTFS can also be interpreted as a two-dimensional code division multiple access (CDMA) scheme, where information symbols are spread in both time and frequency, differently from conventional CDMA systems. In direct sequence CDMA operating in a multipath fading channel, a rake receiver works by combining the delayed components (or echoes) of the transmitted symbols extracted by using matched filters tuned to the respective delay shifts. Similarly, in the case of OTFS, the received delay shifted and Doppler shifted components of the transmitted information symbols can be extracted and coherently combined using linear diversity combining techniques to improve the SNR of the accumulated signal.

We can group the delay-Doppler grid symbols into vectors according to their delay index and reformulate the input output relation between the transmitted and received frames in terms of these transmitted and received vectors. By placing some null symbols (zero-padding (ZP)) in the delay-Doppler domain we arrive at a reduced input-output relation, which allows the use of the maximal ratio combining to design a low complexity detector for OTFS. The overhead of the null guard symbols, needed for the proposed detection scheme, also allows to insert pilot symbols at no additional cost. These null symbols in the delay-Doppler domain act as interleaved ZP guard bands in the time-domain. Taking advantage of this interleaved time-domain ZP, we further present an alternate low complexity time-domain MRC based detection for OTFS.



OTFS with the ZP guard band as mentioned above is similar to the Doppler-resilient orthogonal signal division multiplexing (D-OSDM) scheme recently proposed for under water acoustic channels which is modelled as relatively faster time-varying as compared to the vehicular channel model assumption. Even though the information symbols in both schemes are transmitted in the delay-Doppler domain, the main advantage of the general OTFS transceiver structure is the provision to insert arbitrary frequency domain windowing, which is not a part of the D-OSDM scheme. Windowing allows OTFS to select a subset of sub-carriers for transmission and reception, which is particularly useful in multi-user communication schemes.

Paper is organized as follows. Section II describes OTFS system model and derive the input-output relation in the vector form. The MRC based iterative rake detector, its low complexity implementation and the conditions for convergence are described is given in Section III. Section IV presents simulation results. Finally, Section V presents conclusion.

II. RELATED WORK

In OTFS, the user data (constellation symbols) is placed in the delay-Doppler (De-Do) domain as opposed to TF grid in OFDM. The data is then spread across the TF grid using a unitary transform. This is followed by an OFDM or block OFDM modulator. Cyclic prefix (CP) or block CP is added to absorb the channel delay spread. When OFDM modulation is used with CP, it is called as CP-OTFS whereas, OTFS with block OFDM modulation and block CP is termed as reduced CP OTFS (RCP-OTFS). RCP-OTFS is spectrally more efficient than CP-OTFS.

QAM modulated data symbols, $d(k, l) \in \mathbb{C}, k \in \mathbb{N}[0, N-1], l \in \mathbb{N}[0, M-1]$ are arranged over Do-De lattice $\Lambda = \left\{ \left(\frac{k}{NT}, \frac{l}{M\Delta f} \right) \right\}$. We assume that $E[d(k, l), d(k', l')] = \sigma_d^2 \delta(k - k', l - l')$, where δ is Dirac delta function. Do-De domain data $d(k, l)$ is mapped to TF domain data $X(n, m)$ on lattice $\Lambda^\perp = \{nT, m\Delta f\}, n \in \mathbb{N}[0, N-1], m \in \mathbb{N}[0, M-1]$ by using inverse symplectic fast Fourier transform (ISFFT). $X(n, m)$ can be given as

$$X(n, m) = \frac{1}{\sqrt{NM}} \sum_{k=0}^{N-1} \sum_{l=0}^{M-1} d(k, l) e^{j2\pi \left[\frac{nk}{N} - \frac{ml}{M} \right]} \tag{1}$$

Next, $X(n, m)$ is converted to a time domain signal $s(t)$ through a Heisenberg transform as,

$$s(t) = \sum_{k=0}^{N-1} \sum_{m=0}^{M-1} X(n, m) g(t - nT) e^{j2\pi m \Delta f (t - nT)} \tag{2}$$

Where, $g(t)$ is transmitter pulse of duration T . It has been shown that non rectangular pulse induces non orthogonality which degrades BER performance. Thus, here we consider a rectangular pulse i.e

$$g(t) = \begin{cases} 1, & \text{if } 0 \leq t \leq T \\ 0, & \text{otherwise} \end{cases} \tag{3}$$

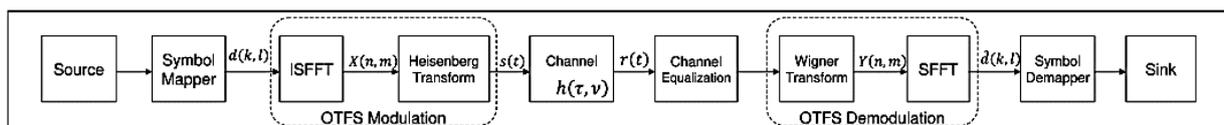


Fig.1. Block diagram of OTFS system

To obtain discrete time representation of OTFS transmission, following the figures 1 and 2, $s(t)$ is sampled at the sampling interval of $\frac{T}{M}$. Samples of $s(t)$ in $s = [s(0), s(1), \dots, s(MN-1)]$ and QAM symbols $d(k, l)$ are arranged in $M \times N$ matrix as,

$$D = \begin{bmatrix} d(0,0) & d(1,0) & \dots & d(N-1,0) \\ d(0,1) & d(1,1) & \dots & d(N-1,1) \\ \vdots & \vdots & \ddots & \vdots \\ d(M-1,0) & d(M-1,1) & \dots & d(N-1,M-1) \end{bmatrix} \tag{4}$$

Using above formulations, \mathbf{s} can be given as,

$$\mathbf{s} = \text{vec}\{\mathbf{D}\mathbf{W}_N\} \tag{5}$$

Alternatively, if $\mathbf{d} = \text{vec}\{\mathbf{D}\}$, then the transmitted signal can also be written as matrix vector multiplication,

$$\mathbf{s} = \mathbf{A}\mathbf{d}, \tag{6}$$

Where, $\mathbf{A} = \mathbf{W}_N \otimes \mathbf{I}_M$ is the OTFS modulation matrix.

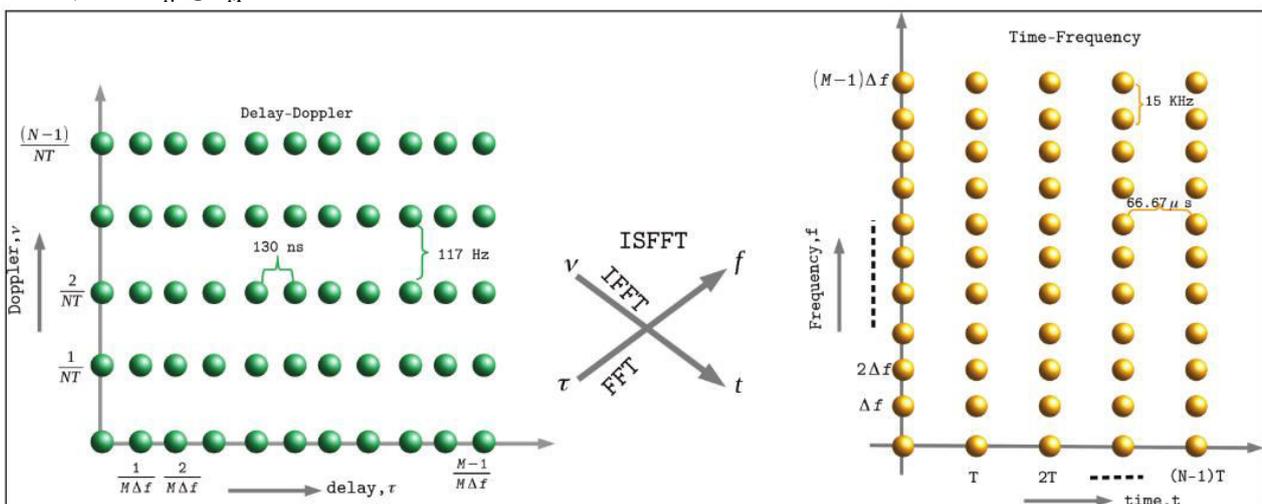


Figure 2 Do-De to TF conversion using inverse symplectic Fourier transform for $N = 128$ and $M = 512$.

The delayDoppler domain symbols in \mathbf{X} is converted to the time-frequency domain (\mathbf{X}_{tf}) using the inverse symplectic fast Fourier transform (ISFFT) operation.

$$\mathbf{X}_{tf} = \mathbf{F}_M \cdot \mathbf{X} \cdot \mathbf{F}_N^\dagger \tag{7}$$

The “Heisenberg transform modulator” generates the time domain signal from the time-frequency samples using an M -point IFFT along with the pulse-shaping waveform $g_{tx}(t)$.The transmitted signal can be written as

$$\mathbf{S} = \mathbf{G}_{tx} \cdot (\mathbf{F}_M^\dagger \cdot \mathbf{X}_{tf}) = \mathbf{G}_{tx} \cdot (\mathbf{X} \cdot \mathbf{F}_N^\dagger) \tag{8}$$

$$\mathbf{G}_{tx} = \text{diag}[g_{tx}(0), g_{tx}(T/M), \dots, g_{tx}((M-1)T/M)] \in \mathbb{C}^{M \times M} \tag{9}$$

Let $\tilde{\mathbf{X}}$ be the matrix containing the delay-time samples before applying pulse shaping waveform and is related to the delay-Doppler domain symbols as

$$\tilde{\mathbf{X}}^T = [\tilde{\mathbf{x}}_0, \dots, \tilde{\mathbf{x}}_{M-1}] = \mathbf{F}_N^\dagger [\mathbf{x}_0, \dots, \mathbf{x}_{M-1}] = \mathbf{F}_N^\dagger \cdot \mathbf{X}^T \tag{10}$$

The time domain vectors $\in \mathbb{C}^{NM \times 1}$, to be transmitted into the physical channel can be written as

$$\mathbf{s} = \text{vec}(\mathbf{G}_{tx} \cdot \tilde{\mathbf{X}}) \tag{11}$$

These samples are pulse shaped and transmitted as a continuous time signal $s(t)$. At the receiver, the delay-time samples are obtained from the sampled received time domain waveform $\mathbf{r} \in \mathbb{C}^{NM \times 1}$ as

$$\tilde{\mathbf{Y}} = \text{vec}_{N,M}^{-1}((\mathbf{I}_M \otimes \mathbf{G}_{rx}) \cdot \mathbf{r}) \tag{12}$$

Where the diagonal matrix G_{rx} has the samples of $g_{rx}(t)$ as its entries:

$$\mathbf{G}_{rx} = \text{diag}[g_{rx}(0), g_{rx}(T/M), \dots, g_{rx}((M-1)T/M)] \in \mathbb{C}^{M \times M} \quad (13)$$

is the pulse shaping filter at the receiver. The received delay-Doppler and delay-time domain symbols are related as

$$\mathbf{Y}^T = [\mathbf{y}_0, \dots, \mathbf{y}_{M-1}] = \mathbf{F}_N [\tilde{\mathbf{y}}_0, \dots, \tilde{\mathbf{y}}_{M-1}] = \mathbf{F}_N \cdot \tilde{\mathbf{Y}}^T \quad (14)$$

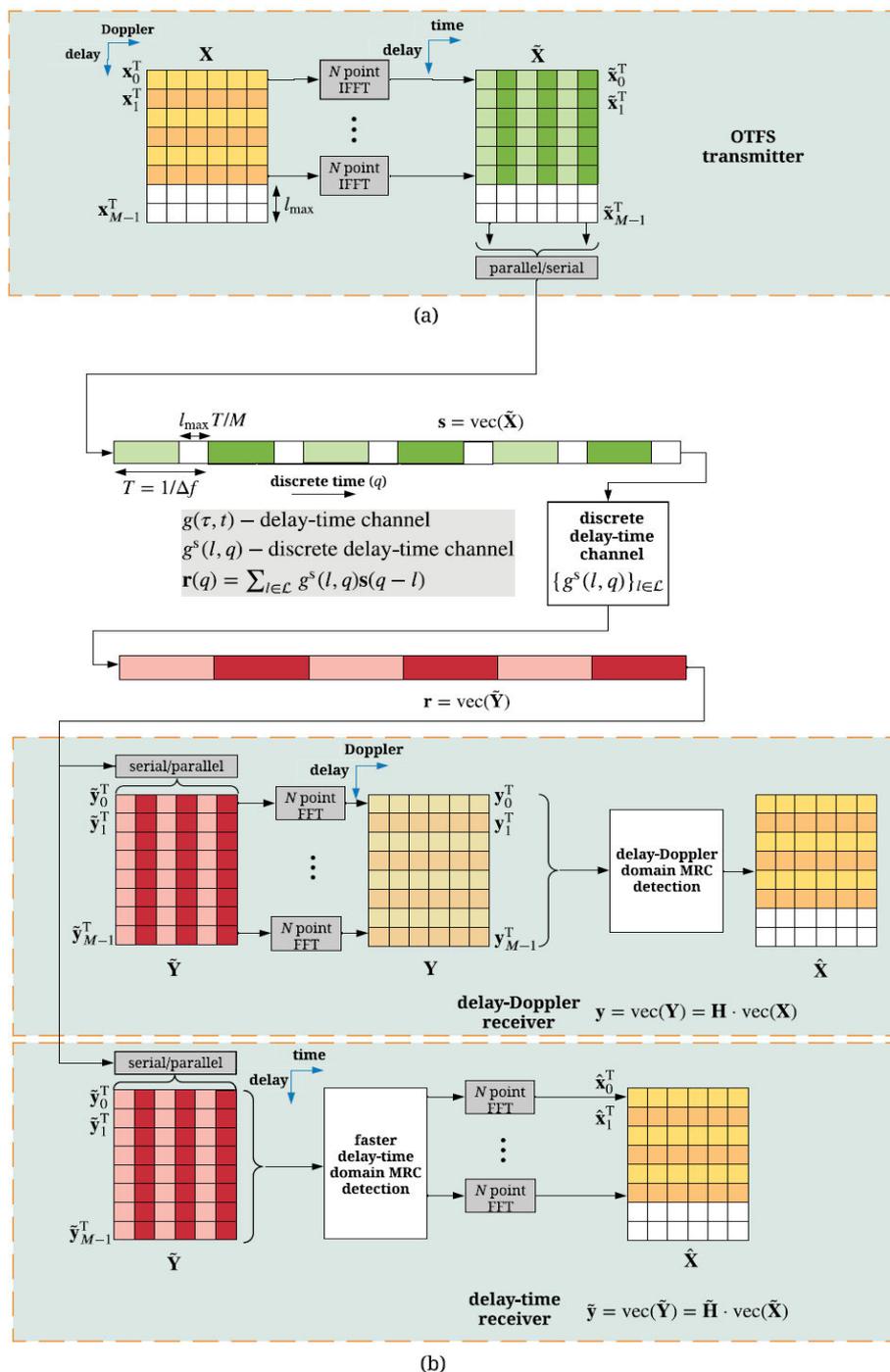


Fig. 3 Discrete baseband model of the ZP-OTFS system for $N = 6, M = 8$ for (a) transmitter (b) receiver



III. METHODOLOGY

We can think of the MRC detector as the maximal ratio combining of the channel impaired signal components received at $L = |\mathcal{L}| \leq P$ different delay branches in the delay-Doppler grid analogous to a CDMA rake receiver. The noise plus interference (NPI) power in each of these branches is different and depends on the channel response. In each detector iteration, we cancel the estimated inter symbol-vector interference in the branches selected for combining, thereby iteratively improving the post MRC signal to interference plus noise ratio (SINR).

The input output relation between the transmitted and received symbol-vectors \mathbf{x}_m and \mathbf{y}_m in is given by

$$\mathbf{y}_{m+l} = \sum_{l \in \mathcal{L}} \mathbf{K}_{m+l,l} \cdot \mathbf{x}_m + \mathbf{w}_{m+l} \quad (15)$$

Where \mathbf{w}_m is iid AWGN noise with variance σ_n^2 . Due to the inter-symbol interference caused by delay spread ($l_{\max} T/M$), all symbol-vectors \mathbf{x}_m have a signal component in L received symbol-vectors \mathbf{y}_{m+l} , for $l \in \mathcal{L}$. Let $\mathbf{b}_m^l \in \mathbb{C}^{N \times 1}$ be the channel impaired signal component of \mathbf{x}_m in the received \mathbf{y}_{m+l} vector at delay index $m+l$ after removing the interference of the other transmitted symbol-vectors \mathbf{x}_k for $k \neq m$. Assuming we have the estimates of symbol-vectors $\hat{\mathbf{x}}_m$ from previous iterations, we can then write \mathbf{b}_m^l for $l \in \mathcal{L}$ as

$$\mathbf{b}_m^l = \mathbf{y}_{m+l} - \sum_{l' \in \mathcal{L}, l' \neq l} \mathbf{K}_{m+l,l'} \cdot \hat{\mathbf{x}}_{m+l-l'} \quad (16)$$

For $l \in \mathcal{L}$, we have L equations for the symbol-vector estimates $\hat{\mathbf{x}}_m$ given as

$$\mathbf{b}_m^l = \mathbf{K}_{m+l,l} \cdot \hat{\mathbf{x}}_m + \mathbf{w}_{m+l} + \text{interference} \quad (17)$$

In the delay branch with index l due to error in the current estimates of the interfering symbol-vectors $\hat{\mathbf{x}}_{m+l-p}$ for $l \neq p$. In this scheme, instead of estimating the transmitted symbol-vector $\hat{\mathbf{x}}_m$ separately from each of the L equations, we perform maximal ratio combining of the estimates \mathbf{b}_m^l followed by symbol-by-symbol QAM demapping. The vector output of the maximal ratio combiner, $\mathbf{c}_m \in \mathbb{C}^{N \times 1}$, is given by

$$\mathbf{c}_m = \mathbf{D}_m^{-1} \cdot \mathbf{g}_m \quad (18)$$

Where

$$\mathbf{D}_m = \sum_{l \in \mathcal{L}} \mathbf{K}_{m+l,l}^\dagger \cdot \mathbf{K}_{m+l,l} \quad (19)$$

$$\mathbf{g}_m = \sum_{l \in \mathcal{L}} \mathbf{K}_{m+l,l}^\dagger \cdot \mathbf{b}_m^l \quad (20)$$

And the hard estimates are given by

$$\hat{\mathbf{x}}_m(n) = \arg \min_{a_j \in \mathcal{Q}} |a_j - \mathbf{c}_m(n)| \quad (21)$$

Where a_j is signal from the QAM alphabet \mathcal{Q} , with $j = 1, \dots, |\mathcal{Q}|$ and $n = 0, \dots, N-1$. Let $\mathcal{D}(\cdot)$ denote the decision on the estimate \mathbf{c}_m in every iteration such that $\hat{\mathbf{x}}_m^{(i)} = \mathcal{D}(\mathbf{c}_m^{(i)})$. Hard-decision function $\mathcal{D}(c)$ is given by the maximum likelihood (ML).

Once we update the estimate $\hat{\mathbf{x}}_m$, we increment m and repeat the same to estimate all $M' = M - l_{\max}$ information symbol-vectors $\hat{\mathbf{x}}_m$ using the updated estimates of the previously decoded symbol-vectors in the form of a decision feedback equalizer (DFE). Note that the DFE action leads to sequential updates whereas alternatively, using only the previous iteration estimates leads to parallel updates. Algorithm 1 shows the delay-Doppler domain MRC operation.

IV. EXPERIMENTAL RESULTS

FER performance of the iterative rake detector vs BICM-OFDM for different code word lengths: long (labelled as SOR-Turbo-Rake-3840) and short (labelled as SOR-Turbo-Rake-672). For a fair comparison with the OFDM scheme, the FER plot for a single turbo iteration is also plotted alongside. It can be observed that, the iterative rake detector with single turbo iteration has a gain of ≈ 3 dB and ≈ 4 dB for code word length of 3840 and 672, respectively, as compared to the OFDM scheme at a FER of 10^{-2} . It can be noted that more iterations are required for short code words to achieve the same performance as long code words.

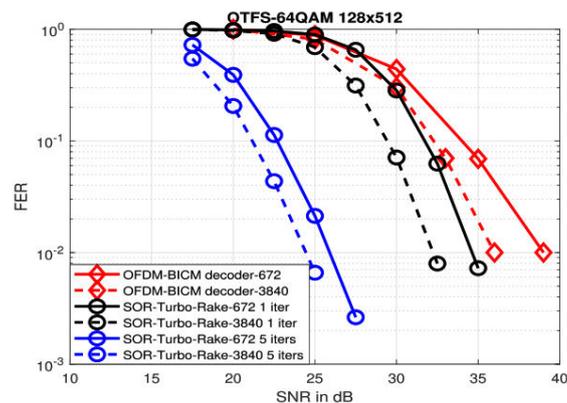


Fig 5. Turbo 64-QAM FER Plot: MRC vs BIC-MMSE-OFDM for codeword lengths: 672, 3840

V. CONCLUSION

MRC detector along with a low complexity initial estimate of symbol-vectors can achieve similar or better BER performance than the MPA detector with lower complexity and storage requirements. The MRC detector performance can be further improved with the aid of an outer error control coding scheme using turbo iterations. An additional advantage of the MRC detector is that the complexity is linear in L (number of delay taps) rather than P (total number of paths), thanks to the vector decomposition of the 2-D convolution with the channel.

REFERENCES

- [1] T. Thaj and E. Viterbo, "Low Complexity Iterative Rake Decision Feedback Equalizer for ZeroPadded OTFS Systems", in IEEE Transactions on Vehicular Technology, vol. 69, no. 12, pp. 1 5606-15622, Dec. 2020, doi: 10.1109/TVT.2020.3044276.
- [2] T. Thaj and E. Viterbo, "Low Complexity Iterative Rake Detector for Orthogonal Time Frequency Space Modulation" 2020 IEEE Wireless Communications and Networking Conference (WCNC), 2020, pp. 1 -6, doi: 10.1109/WCNC45663.2020.9120526
- [3] Y. Hong, T. Thaj, E. Viterbo, "Delay-Doppler Communications: Principles and Applications", Academic Press, 2022, ISBN: 9780323850285
- [4] P. Raviteja, K. T. Phan, Y. Hong and E. Viterbo, "Interference Cancellation and Iterative Detection for Orthogonal Time Frequency Space Modulation" in IEEE Transactions on Wireless Communications, vol. 17, no. 10, pp. 6501 -6515, Oct. 2018, doi: 10.1109/TWC.2018.2860011
- [5] Li Li, H. Wei, Y. Huang, Y. Yao, W. Ling, G. Chen, P. Li, and Y. Cai, "A simple two-stage equalizer With simplified orthogonal time frequency space modulation over rapidly time-varying channels," available online: <https://arxiv.org/abs/1709.02505>.
- [6] T. Thaj, E. Viterbo and Y. Hong, "Orthogonal Time Sequency Multiplexing Modulation: Analysis and Low-Complexity Receiver Design" in IEEE Trans. on Wireless Commun., 2021
- [7] T. Ze me n, M. Hofer, and D. Loeschenbrand, "Low-complexity equalization for orthogonal time and frequency signalling (OTFS)," available online: <https://arxiv.org/pdf/1710.09916.pdf>
T. Thaj and E. Viterbo, "Orthogonal Time Sequency Multiplexing Modulation," Proc. IEEE Wireless Commun. and Netw. Conf. (WCNC), 2021, pp. 1-7.



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