Index Modulation Assisted Zero-Padded Tri-Mode OTFS

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Abstract

Orthogonal time frequency space with index modulation (OTFS-IM) has been considered a promising technique for improving the bit error rate (BER) in high mobility environments. To further improve the BER and spectral efficiency here zero-padded tri mode index modulation is proposed with OTFS modulation (ZTM-OTFS-IM). Some information symbols on delay doppler resource blocks (DDRBs) are modulated with two distinguishable constellations and rest of the DDRBs remain inactive. Through this approach, extra bits can be transmitted by the subcarrier indices that correspond to the two constellation sets. The ZTM-OTFS-IM presented has the ability to improve both the spectrum and energy efficiency when compared to previous index modulated OTFS, dual mode OTFS-IM and OTFS methods. Simulation results show the reduction in BER using Index Modulation assisted ZTM OTFS as compared to Dual Mode OTFS-IM and traditional OTFS-IM.

Keywords: Index modulation (IM), OTFS-IM, Zero-Padded Tri-Mode OTFS

Ⅰ. Introduction

Researchers are seeking novel and supplementary methods to address the growing need for high-speed mobile wireless communications via channels with limited bandwidth. [1]. The orthogonal time frequency space (OTFS) modulation technique is a highly promising option for reducing the bit error rate (BER) in highly mobile environments, in comparison to traditional orthogonal frequency division multiplexing (OFDM) [2]. This is because OTFS utilizes delay and Doppler parameters to modulate information symbols, making it a robust choice for channels that are selective in both time and frequency.

In recent years, index modulation (IM) approaches have made significant contributions to the comprehension of spectrum efficiency, energy efficiency, and bit error rate (BER). Dual Mode OTFS-IM technique has been presented in [2] in which some DD resources are activated on incoming bits with one modulation order and rest of the resources are utilized with another constellation. The ZTM-OFDM-IM as discussed in [1] uses two different constellations and some resources are still empty to mitigate the inter-symbol interference.

This work proposes a technique called zero-padded tri-mode index modulation aided OTFS (ZTM-OTFS), which involves dividing Delay Doppler Resource into subblocks. Within each OTFS subblock, a portion of subcarriers are modulated using two distinct constellation alphabets, while the other subcarriers are left unmodulated. Data symbols can carry information bits and activated DD resources can likewise convey information through their indices. At the receiver, demodulation is performed using maximum-likelihood (ML) detector.

II. System Model

Fig. 1 presents the system model for the proposed index Modulation assisted ZTM-OTFS. The transmitting B bits are divided into G groups containing b_{ZTM} bits. In each group, b_{ZTM} bits are further divided into b_1 modulation bits and b_2 Index bits. Out of total MN delay Doppler resource blocks, where M is the number of resources along the delay axis and N is the number of resources along the Doppler axis, each group contains $n = \frac{MN}{G}$ DDRBs. The first bits $b_2 = \left\lfloor log_2\left(\binom{n}{k} \times \binom{k}{k_1}\right)\right\rfloor$ are utilized to choose a specific arrangement of k active DDRB from a total of n, with the remaining $n - K$ DDRB being assigned a value of zero. Here k_1 and $k_2 = k - k_1$ DDRBs are used for modulation $\mathcal{M}_1$ (Mapper 1) and $\mathcal{M}_2$ (Mapper 2) respectively. An example of arrangement of active DDRB and distinct modulations is shown in the table 1.

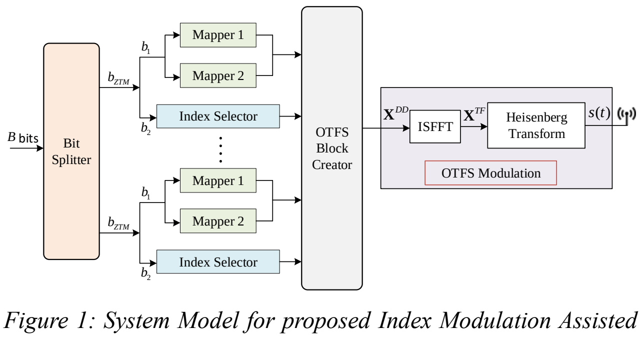

Figure 1: System Model for proposed Index Modulation Assisted ZTM OTFS

The $b_1 = k_1 log_2(\mathcal{M}_1) + k_2 log_2(\mathcal{M}_2)$ modulation bits are modulated on two different constellations defined by $\mathcal{M}_1$ and $\mathcal{M}_2$. Now the total number of information bits that can be transmitted by the proposed index modulation assisted ZTM-OTFS are given by

$$b_{ZTM} = k_1 log_2(\mathcal{M}_1) + k_2 log_2(\mathcal{M}_2) + \left\lfloor log_2\left(\binom{n}{k} \times \binom{k}{k_1}\right)\right\rfloor \quad (1)$$

After getting the data symbols $(x_\gamma^1, x_\gamma^2 \dots x_\gamma^G)$ to transmit from each group, is combined to make single OTFS frame for OTFS modulation. Here γ represents the number constellation being used for modulation. Then, Inverse Symplectic finite Fourier transform (ISFFT) is applied to convert DD domain symbols $x[k,l]$ to Time-frequency (TF) domain symbols $X[n,m]$ and then form TF to time domain signal $s(t)$ using Heisenberg transform.

$$X[n,m] = \frac{1}{MN} \sum_{k=0}^{N-1} \sum_{l=0}^{M-1} x[k,l] e^{j2\pi\left(\frac{nk}{N} - \frac{ml}{M}\right)} \quad (2)$$

where $n \in (1,2,\dots N)$ and $m \in (1,2,\dots M)$.

$$s(t) = \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} X[n,m] e^{j2\pi m\Delta f(t-nT)} g_{\text{tx}}(t-nT) \quad (3)$$

where $g_{tx}(t)$ is the transmit pulse function. The time domain signal will undergo a DD domain channel $h(\tau,\nu)$, given in [2].

Table 1: An example of a lookup table for k=2, k_1 =1, k_2=1 and n=4.

Index Bits	Activation Pattern
000	$[\mathcal{M}_1, \mathcal{M}_2, 0, 0]$
001	$[\mathcal{M}_1, 0, \mathcal{M}_2, 0]$
010	$[\mathcal{M}_1, 0, 0, \mathcal{M}_2]$
011	$[0, \mathcal{M}_1, \mathcal{M}_2, 0]$
100	$[0, \mathcal{M}_1, 0, \mathcal{M}_2]$
101	$[0, 0, \mathcal{M}_1, \mathcal{M}_2]$
110	$[\mathcal{M}_2, \mathcal{M}_1, 0, 0]$
111	$[\mathcal{M}_2, 0, \mathcal{M}_1, 0]$

The received time domain signal at the receiver is given by

$$r(t) = \iint h(\tau,\nu) e^{j2\pi\nu(t-\tau)} s(t-\tau) d\tau d\nu + z(t) \quad (4)$$

where $z(t)$ is additive white Gaussian noise. The TF domain signal is extracted from the time domain signal using the Wigner transform and is converted to DD domain signal by employing the Symplectic finite Fourier transform (SFFT).

$$Y[n,m] = \int_{-\infty}^{\infty} g_{\text{rx}}^*(t-nT) r(t) e^{-j2\pi m\Delta f(t-nT)} dt \quad (5)$$

$$y[k,l] = \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} Y[n,m] e^{-j2\pi\left(\frac{nk}{N} - \frac{ml}{M}\right)} \quad (6)$$

where $g_{\text{rx}}(t)$ is the received pulse function.

III. Results

In the figure 2 a simulation-based BER comparison of proposed index modulation assisted ZTM-OTFS, dual mode OTFS-IM, OTFS-IM and OTFS is presented. A doubly spread channel $h(\tau,\nu)$ model is considered with delay profile of Extended Vehicular A (EVA) model and max doppler shift is 1KHz. The modulation order in each technique is selected to produce a constant spectral efficiency to have fair comparison of BER. The ZTM-OTFS-IM exhibits superior performance in terms of bit error rate (BER) compared to other techniques stated. This is because ZTM-OTFS-IM has the capability to practically transfer more bits through index information, while utilizing fewer active resources.

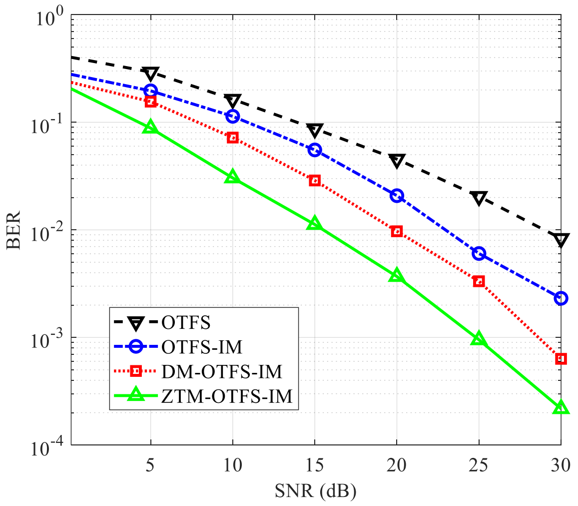

Figure 2: BER comparison of proposed ZTM-OTFS-IM (k=2, k_1 =1, k_2=1, M_1 =8, M_2 =2), DM-OTFS-IM (k_1 =2, k_2=2, M_1 =4, M_2 =2), OTFS-IM (k=3, M=4), OTFS (M=4).

IV. Conclusion

Considering the BER values across different SNR levels, ZTM-OTFS-IM appears to offer superior performance compared to OTFS, OTFS-IM, and DM-OTFS-IM in terms of error rate, making it a promising choice for communication systems where reliability and robustness are crucial.

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