Index Modulated Orthogonal Time Frequency Space Multiplexing Assisted by Lower Order Modulations

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Abstract

Orthogonal time frequency space with index modulation (OTFS-IM) transmits information through predefined subcarriers' activation patterns and M-ary constellation symbols. OTFS-IM outperforms the Orthogonal frequency division multiplexing with index modulation (OFDM-IM) in highly mobile environments. OTFS-IM can improve the bit error rate performance compared to conventional OTFS while keeping the spectral efficiency (SE) constant due to transmitting the information symbols on index-based selected delay Doppler resources. Since OTFS-IM does not use all subcarriers to transmit information in the delay Doppler resources index domain, some resource blocks remain unused. To keep the same SE, OTFS-IM modulates the information symbols on a higher constellation, increasing BER. This paper presents a technique in which OTFS-IM symbols are modulated with lower order modulation (LO-OTFS-IM), keeping the SE constant by shifting the information bits towards the index domain. Simulation results show the reduction in BER using LO-OTFS-IM as compared to OTFS-IM.

Keywords: Index modulation (IM), Lower order modulation, OTFS, OTFS-IM

Ⅰ. Introduction

Researchers are looking for innovative and complementary solutions to the current communications systems due to the rapidly increasing demand for high-speed mobile wireless communications over channels with restricted bandwidth. [1]. The orthogonal time frequency space (OTFS) modulation technique is the most promising candidate for the reduction in bit error rate (BER) in highly mobile environments as compared to traditional orthogonal frequency division multiplexing (OFDM) [2] since OTFS uses the delay and doppler parameters to modulate the information symbols, making it a robust candidate for doubly (time and frequency) selective channels.

Index modulation (IM) techniques have contributed to a deeper understanding of spectrum efficiency, energy efficiency, and bit error rate (BER) in recent years. As highlighted in reference [3], it has been possible to establish an attractive trade-off between spectral and energy efficiency using IM for various application scenarios. In IM, the index of the transmitting resources, here the Delay Doppler Resource Blocks (DDRB), are used to transmit additional information.

The authors of this paper suggest a lower-order modulation-assisted OTFS-IM (LO-OTFS-IM) to improve the BER and SE of OTFS-IM. Reusing some index combinations of conventional OTFS-IM with the help of distinguishing lower-order constellation modes increases the number of index bits rather than requiring a larger constellation size to improve SE at the price of BER.

II. System Model

Fig. 1 presents the system model for the proposed LO-OTFS-IM. The transmitting B bits are divided into G groups containing b bits. In each group, b bits are further divided into b_1 index bits and b_2 constellation bits. Out of total MN delay Doppler resource blocks, where M is the number of resources along the delay axis and cap N is the number of resources along the Doppler axis, each group contains $= \frac{MN}{G}$ DDRBs. In eachutilizedck, the first bits $b_1 = \lfloor log_2\binom{n}{K} \rfloor$ are utilised to choose a specific arrangement of K active subcarriers from a total of n, with the remaining $n - K$ subcarriers being assigned a value of zero.

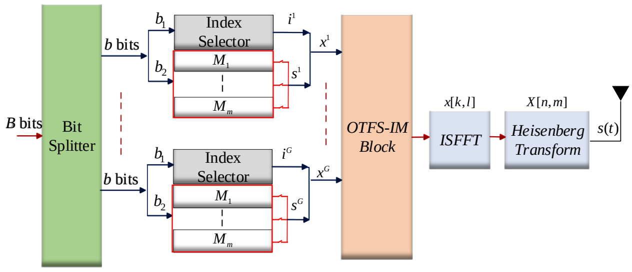

Figure 1: System Model for proposed LO-OTFS-IM

A lookup table (LUT) in Table I exemplifies an index pattern. A lower-order modulation $\mathcal{M}_1$ is used to transmit $b_2 = log_2\mathcal{M}_1$ bits over K active subcarriers instead of higher modulation order $\mathcal{M}'$ where $(\mathcal{M}' > \mathcal{M}_1, \mathcal{M}' > \mathcal{M}_2)$. By using the lower modulation order, the remaining $\mathcal{P} = Klog_2\mathcal{M}' - Klog_2\mathcal{M}_1$ bits are adjusted in index information by reusing the phase rotated in the same modulation order, as shown in Table 1.

Table 1: An example of a lookup table for K=1(represented by ζ) and n=4

Index Bits	Modulation	Activation Pattern
000	$\mathcal{M}_1 = [-1,1]$	$[\zeta, 0,0,0]$
001		$[0, \zeta, 0,0]$
010		$[0,0, \zeta, 0]$
011		$[0,0,0, \zeta]$
100	$\mathcal{M}_2 = \mathcal{M}_1 \times \exp\left(\frac{\pi j}{2}\right)$	$[\zeta, 0,0,0]$
101		$[0, \zeta, 0,0]$
110		$[0,0, \zeta, 0]$
111		$[0,0,0, \zeta]$

The incoming bits are converted to data symbols based on lower-order modulation. $(\mathcal{M}_1, \mathcal{M}_2)$ selected by index selector. After getting the data symbols $(x^1, x^2 \dots x^G)$ to transmit from each group, is combined for OTFS modulation. Then, Inverse Symplectic finite Fourier transform (ISFFT) is applied to convert DD domain symbols $x[k,l]$ to Time-frequency (TF) domain symbols $X[n,m]$ given by

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

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

And then form TF to time domain signal $s(t)$ using Heisenberg transform.

$$s(t) = \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} X[n,m] e^{j2\pi m \Delta f (t-nT)} g_{\text{tx}}(t-nT) \qquad (2)$$

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

$$h(\tau, \nu) = \sum_{p=0}^{P} h_p \delta(\tau - \tau_p) \delta(\nu - \nu_p) \qquad (3)$$

where P is the number of multipaths. The received time domain signal at the receiver is given by

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

where $z(t)$ is additive white Gaussian noise. The TF domain signal is extracted from the time domain signal using the Wigner transform.

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

where $g_{\text{rx}}(t)$ is the received pulse function. Finally, the DD domain signal is obtained from the TF domain signal by employing the Symplectic finite Fourier transform (SFFT).

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

The maximum likelihood detector is used to identify the information from the modulated symbols and their corresponding indices.

III. Results

Figure 2 presents the simulation-based comparison of proposed LO-OTFS-IM and conventional OTFS-IM techniques. Due to the higher modulation used in the traditional OTFS-IM scheme to match the spectral efficiency of the OTFS technique employing all the DDRBs, a performance reduction in BER is expected and can be seen in Figure 2 compared to the proposed LO-OTFS-IM technique. The proposed LO-OTFS-IM shows an improvement of 7-8 dB SNR at BER of 10^{-4}.

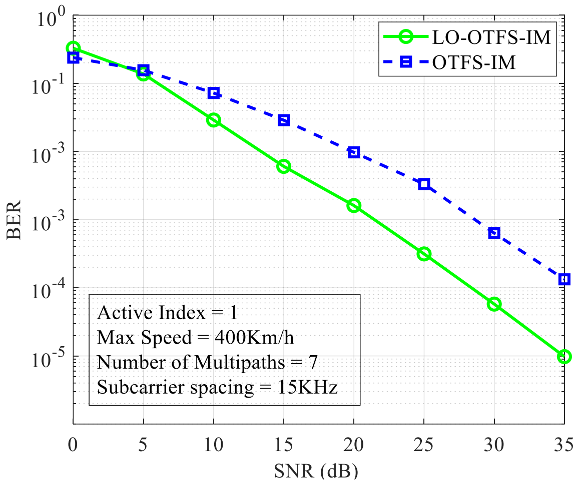

Figure 2: BER comparison of proposed LO-OTFS-IM and conventional OTFS-IM

IV. Conclusion

Employing lower modulation orders with OTFS-IM can improve the BER performance of the communication system compared to conventional OTFS-IM with higher modulation orders.

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