IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⁙ Peer-reviewed & Refereed journal ⁙ Vol. 15, Issue 7, July 2026

DOI: 10.17148/IJARCCE.2026.15727

Advanced time frequency approaches in SMOTFS and OTFS for wireless system

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Abstract: The fifth generation (5G) mobile communication system is looking forward to achieving much better spectral efficiency, higher mobility, and lower end-to-end latency in comparison with the fourth-generation (4G) system. To deal with the influence of the fast time-varying wireless mobile channels, orthogonal time frequency space (OTFS) modulation has been proposed. Orthogonal Time Frequency Space (OTFS) is a 2dimensional (2D) modulation technique designed in the delay-doppler domain which has the strong doppler-resilience over doubly selective channels and SM-OTFS system by the joint design of SM and OTFS modulation and to achieve the improved spectral efficiency and enhanced transmission reliability of the OTFS system when compared to OFDM and OTFS.

Keywords: Orthogonal Time Frequency Space (OTFS), Delay Doppler, spatial modulation-OTFS (SM-OTFS), Orthogonal Frequency Division Multiplexing (OFDM), Sixth generation(6G), Delay doppler domain (DD domain), Time frequency domain (TF domain)

1. INTRODUCTION

The 4G modulation of Orthogonal Frequency Division Multiplexing (OFDM) breaks down in this setting as channel estimation is no longer effective.

Aim of next generation communication is to handle terahertz frequency with enlarged channel for that they used Haptic communication is monitored by the facility of 6G specialized functions. Also pointed out the possible applications and the technologies to be deployed for 6G communication [1].

The different satellites are, in fact, characterized by different Doppler-delay pairs and channel gains, making the scenario similar to the case of a wireless channels with different scatterers, thus allowing a significant performance improvement with respect to a scenario where each user is served by a single satellite. They discussed about the comparison with the existing new radio (NR) air interface, i.e., based on the OFDM modulation, showed that OTFS provides a better solution to enable cell-free satellite architectures. This modulation format, proposed for doubly-selective terrestrial channels, can allow to exploit diversity in case of multiple satellites transmitting the same OTFS signal [2].

The development progress and methods like massive MIMO, Dense networks, Millimetre-Wave Technologies are involved and compared the advantages of this new technology (6G) with already existing technology (5G) [3].

They demonstrated the effectiveness of the proposed coordinated multi-satellite transmission, SP-ACE and three stage PSC-based fractional Doppler estimation schemes. SP-ACE scheme for efficiently dealing with different delay and Doppler offsets among cooperative LEO satellites, which estimates the channels in S2G joint transmission by regarding the channels of all cooperative links as a single channel to reduce channel estimation complexity and improve channel estimation performance. Considering integer and fractional Doppler cases, three-stage PSC fractional Doppler frequency shift estimation are included through simulation [4]

The different satellites are, in fact, characterized by different Doppler-delay pairs and channel gains, making the scenario similar to the case of a wireless channels with different scatterers, thus allowing a significant performance improvement with respect to a scenario where each user is served by a single satellite [5]

It focus on the scenario of multiple spectrum bands in the common pool of auction but each bidder is allocate most one spectrum band. Through analysis and simulation it represent the popular conception of concurrent auction does not prove beneficial with two metrics, revenue generated by auctioneer and optimal bid of the bidders for comparison of sequential and concurrent auctions. We have shown that sequential auction proves to be the better choice for DSA auctions [6]

It discussed about the 6G communication network specification, Terahertz communication, Energy effectiveness, Ultra-Dense Networks and other aspects. It address challenges faced on above network with various potential solutions and technologies have been identified [7]

The CSI-PNet (with two different design variants) and ACSI-PNet used to based on 3D-CCNN (3D complex valued CNNs). These networks have the capabilities to capture the spatial and temporal correlation that show gains especially at low and medium speeds. They evaluate the performance of the new methods have two datasets. One is a synthetic dataset using an outdoor UMa 3GPP channel model. The other is based on measurements in a commercial network. The correction of TFO (Time and Frequency Offset) plays a major role in the performance [8]

. Technology components such as cell-free or distributed massive MIMO, sub-THz elec tronics, SWIPT and satellite communication are all possible enablers in the evolution toward 6G. Advanced OTA methods it is possible to evaluate link performance and even noise figure, other RF parameters, and maximum link ranges based on Error Vector Magnitude (EVM) and signal processing complexity and quality requirements are proportional to sampling speed and accuracy, the prototyping of high-speed links is typically done using simple single carrier type modulations and relatively low Signal-to-Noise Ratio (SNR) requirements are discussed in it [9]

The fraction of sensing resources can even be co-used for both data transmission and sensing when the cell is loaded suitably enough. 6G systems will very likely have AI/ML processing from scratch, as well as massive and distributed MIMO in their design. These will also be welcome tools for processing the JCAS signals. Distributed coordinated base stations both boost robustness of communication systems to meet extreme reliability requirements as well as provide attractive dis tributed radar system possibilities, especially in the Industrial Internet of Things environment on factory. Further research on several different aspects is needed for optimal design of JCAS systems to fully realize the vision of widespread sensing through cellular systems [10]

2. PROPOSED SYSTEM

2.1 SMOTFS

The proposed system combines Orthogonal Time Frequency Space modulation (OTFS) with Spatial Modulation (SM) to improve reliability and spectral efficiency in high-mobility wireless environments.

In the SM-OTFS framework, information bits are divided into:

- **Symbol bits** → mapped to constellation symbols
- **Spatial bits** → used to select the active transmit antenna

At any given time instant, only one transmit antenna is active, reducing inter-channel interference and RF complexity. In SM, only one antenna is active at a time – the index of the active antenna conveys additional bits of information. So, the data transmitted not only by modulated symbols but also by antenna indices. For example, if there are $N_t = 4$ antennas, 2 bits ($\log_2(4)$) can be sent just by selecting the active antenna.

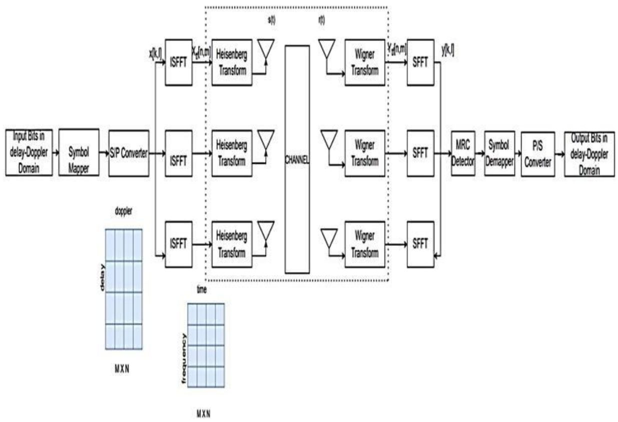

Figure1 Overall system model

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a) TRANSMITTER SIDE

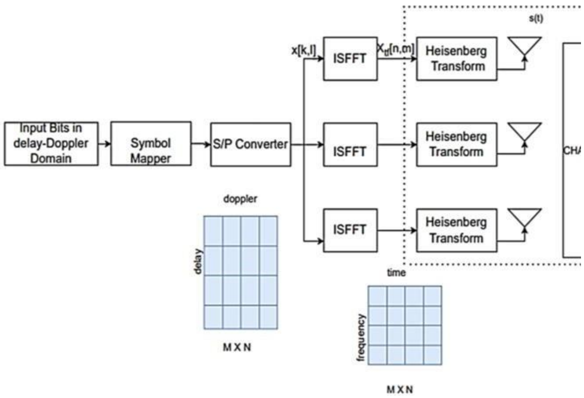

Figure 2 Transmitter side model

At first, the random input bits are mapped on the delay doppler domain using QAM symbols,

b = [1 0 1 1 1 0 0 1 0 1 0 1]

After symbol mapping binary matrix Q is formed and transmitted in one SM-OTFS transmit frame via serial-to-parallel (S/P) converter

$$Q = \begin{bmatrix} 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & 1 \end{bmatrix}.$$

After this process, the transmitter converts the delay-Doppler domain signals in each row vector of X into the time-frequency domain signals by the ISFFT at each transmit antenna. Then the different transmit antennas will transform the input time-frequency domain signals into the time-domain
signals S_i (t) by the Heisenberg transform shown as,

$$S_i(t) = \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} X_i[n,m] a_{tx}(t-nT) e^{j2\pi m\Delta f(t-nT)}$$

According to the mapping rule in table1, Q is transformed to matrix X after Spatial Modulation and X is written as,

$$X = \begin{bmatrix} 0 & 0 & +1+i & 0 \\ -1-i & +1+i & 0 & -1-i \end{bmatrix}$$

The transmit signal matrix with time domain components for all the transmit antennas can be represented as S(t). Each row of S (t) is then sent to the receiver simultaneously from N_t different antenna variant MIMO channel H(t). Here the time-variant multipath Rayleigh fading channel is employed, where the channel delays and Doppler shifts corresponding to each path are different.

System configuration: N_t = 2, M_s = 4		
Input bits	**Antenna index**	**Transmit Signal**
000	1	-1+i
001	1	-1-i
010	1	+1+i
011	1	+1-i
100	2	+1+i
101	2	-1-i
110	2	+1+i
111	2	+1-i

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b) **OTFS MODULATION**

The modulated symbols are arranged in the delay-Doppler (DD) domain grid of size M×NM \times NM×N.

The transformation from delay-Doppler domain to time-frequency domain is performed using the Inverse Symplectic Finite Fourier Transform (ISFFT):

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

Then, Heisenberg transform converts the signal into the time domain waveform for transmission.

c) **Channel Model**

The wireless channel is modeled as a doubly selective channel with both delay and Doppler effects.

The channel impulse response in delay-Doppler domain is:

$$X[n,m] = \sum_{p=1}^{P} hp\delta(\tau - \tau p)\delta(v - vp)$$

where:
hp → complex gain τp→ delay
vp → Doppler shift

d) **Receiver side**

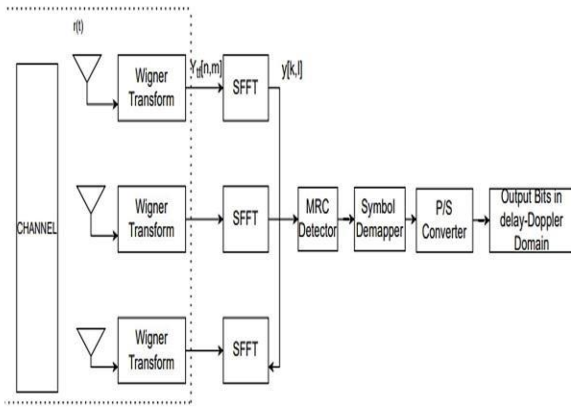

Figure 3 Receiver side model

The receiver processes the incoming signal from the doubly selective wireless channel and recovers the transmitted information symbols and antenna indices. The received signal is first converted into the delay-Doppler domain, followed by diversity combining, symbol detection, and bit reconstruction.

The received signal from the MIMO channel is first processed using the Wigner transform to obtain the time-frequency representation. This is followed by SFFT to convert the signal into the delay-Doppler domain. The signals from multiple receive antennas are then combined using Maximum Ratio Combining (MRC) to improve signal quality. The combined signal is passed through a symbol detector and demapper to recover the transmitted bits. Finally, parallel-to-serial conversion reconstructs the original bit stream.

The received signal at the rth antenna is given by:

$$y_r(t) = \sum_{i=1}^{Nt} h_{r,i}(t) * x_i(t) + n_r(t)$$

Where, $h_{r,i}(t)$ is a channel between transmit antenna and receive antenna, $x_i(t)$ is a transmitted signal and $n_r(t)$ is a AWGN noise.

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Wigner transform is used to Captures both time and frequency variations and Prepares signal for OTFS demodulation Each received signal is passed through the **Wigner Transform**, which converts the time-domain signal into the time-frequency.

$$Y_r(t,f) = \int y_r(t+\frac{\tau}{2})y_r^*(t-\frac{\tau}{2})e^{-j2\pi f\tau} d\tau$$

The output of the Wigner transform is converted into the delay-Doppler domain using **Symplectic Finite Fourier Transform (SFFT)**. It recovers the signal in delay-Doppler grid and exploits channel sparsity

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

The outputs from multiple receive antennas are combined using **Maximum Ratio Combining (MRC)**. It maximizes Signal-to-Noise Ratio (SNR) and provides diversity gain.

$$x^{\wedge} = \sum_{r=1}^{N_r} h_r^* y_r$$

After combining, the transmitted symbol is detected using decision rules. The Maximum Likelihood used for further improvement. Eventually, Maximum Ratio Combining (MRC) detection is used to detect the signals. It is applied at the receiver to combine the signals received from different antennas. The combining is done by adjusting the weights of the signals from each antenna based on the channel conditions. MRC gives more weight to signals with better channel conditions, effectively improving the overall signal quality. After MRC combining, symbol detection is performed based on the combined signal. The detected symbol and the selected transmit antenna provide the information transmitted in that particular time slot.

$$x^{\wedge} = argmin_{x\in s} \|y-hx\|^2$$

Symbol Demapper is used for the detected complex symbols are mapped back to bits based on modulation scheme (e.g., QPSK, QAM). The combined signal is associate it with the most likely transmitted symbols.

$$b^{\wedge} = Demap\,(x^{\wedge})$$

The demapped bits are converted from parallel streams into a serial bit sequence in Parallel-to-Serial (P/S) Conversion. The demapping process is not only about selecting a symbol from a constellation but also identifying the active transmit antenna.

$$b_{out} = P/S(b^{\wedge})$$

The final output represents the recovered bit stream corresponding to the transmitted delay-Doppler symbols**.** The input-output relationship of the SM-OTFS system has been derived for transmission over doubly-selective channels. By exploiting the properties of SM, a symbol mapper has been introduced for deriving the input-output relationship of SM OTFS. Furthermore, a low-complexity detector has been proposed for SM-OTFS systems.

3. PERFORMANCE OF SMOTFS SYSTEM

3.1 Input bits

The random bits have been generated for the whole system where the input bits are plotted in delay doppler grid for the compact and clear view of the generated signal.

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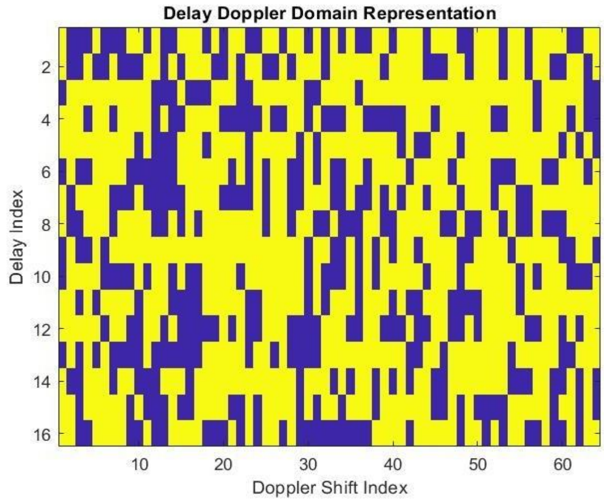

Figure 4: DD domain plotted by random bits

3.2 Original & Reflected time domain signal

The different transmit antenna will transform the input time-frequency domain signals into the time domain signals by the Heisenberg transform. The transmit signal matrix with time domain components for all the transmit antenna can be represented as S(t) as shown in below figure.

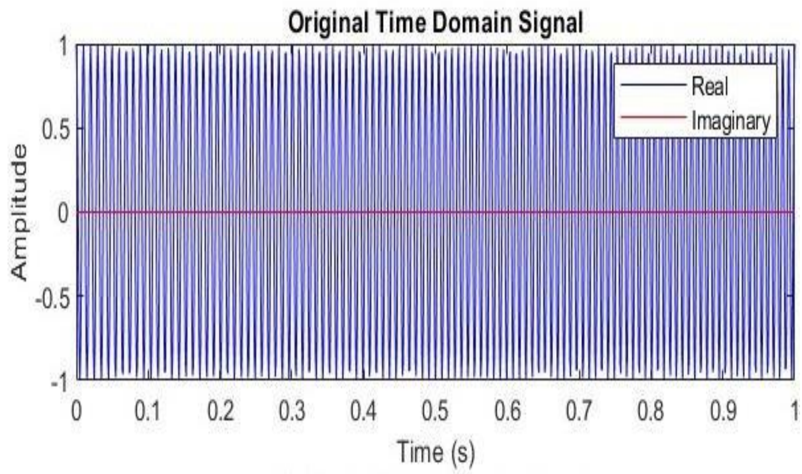

Figure 5: Original time domain signal

The resulting time-domain signal vectors are sent simultaneously to the receiver. To illustrate the operation of the SM-OTFS system intuitively, suppose that the receiver can acquire all the CSI by perfect channel estimation, while there exists no noise interference during the signal transmission.

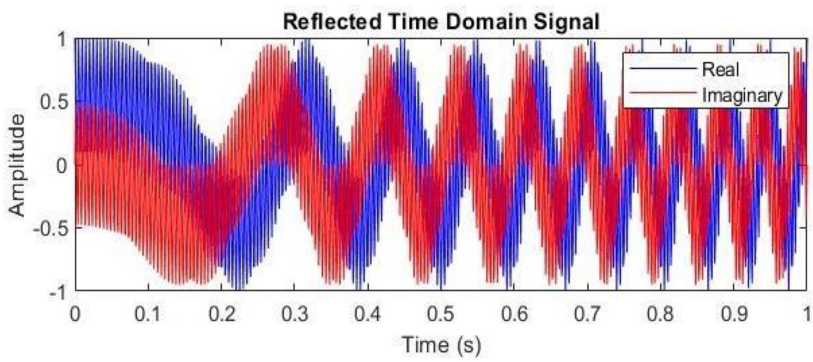

Figure 6: Reflected time domain signal

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3.3 Time frequency domain by SFFT

The received time domain signal gets converted to time frequency domain by Wigner transform and SFFT.

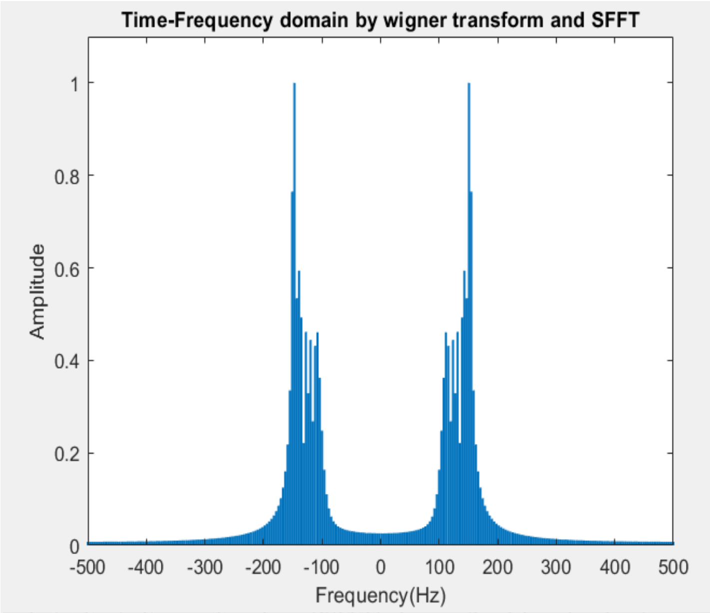

Figure 7: TF domain by SFFT

3.4 DD domain and TF domain

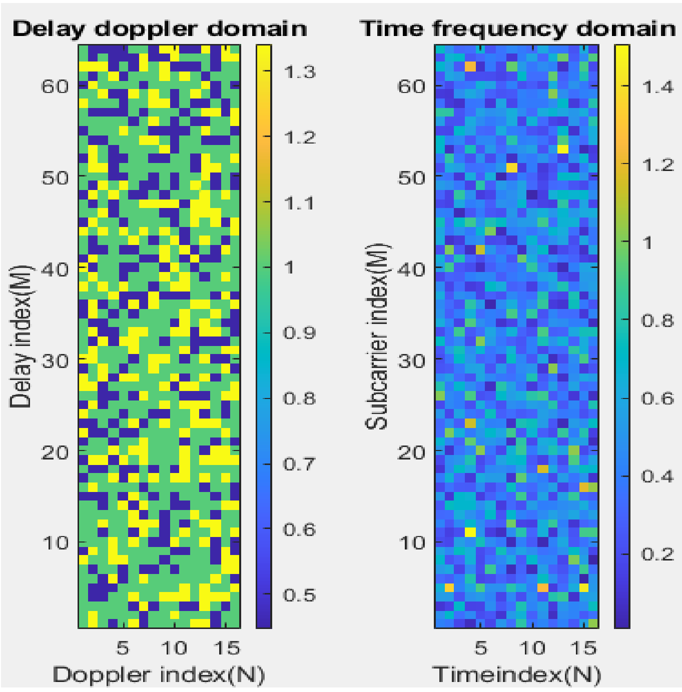

Figure 8: DD & TF domain

Delay doppler domain shows random yellow-green patches – showing amplitude variations in delay and doppler bins. It shows how multipath components spread in delay and doppler.

Time Frequency domain shows more smooth blue-green – represent how the same data spreads over time and frequency after transformation. It is used for actual signal transmission via multicarrier modulation.

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3.5 TF domain

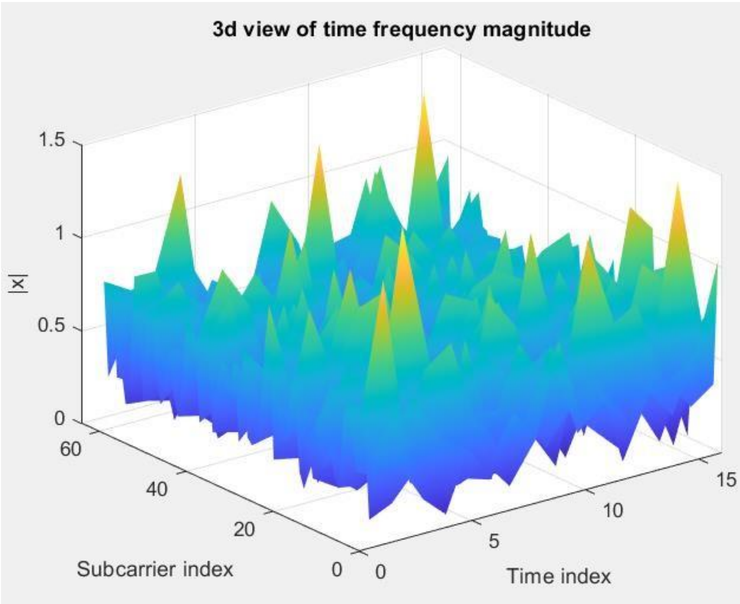

Figure 9 3dimensional view of TF domain

The above figure represents the combined form of time and frequency magnitude in 3Dimensional view.

3.6 Output bits in DD domain

Eventually, after the MRC or ML detection in the receiver, the output delay Doppler information bits can be retrieved according to the SM de-mapping rule via parallel-to-serial (P/S) converter and the output bits is viewed in delay-doppler domain.

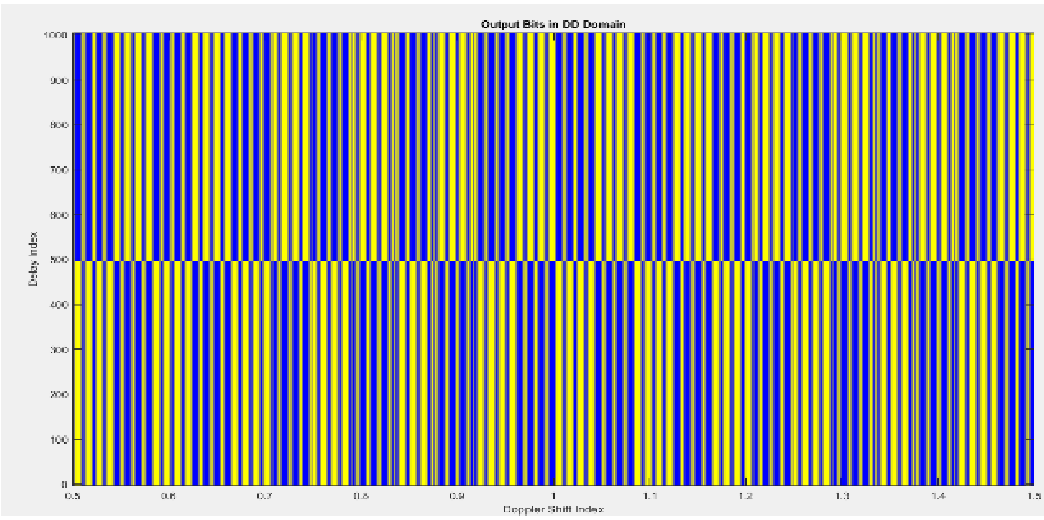

Figure 10 Output in grid form

4 RESULT ANALYSIS

4.1 BER performance

The BERs of both OFDM and OTFS improve with the number of transmit and receive antennas, but OTFS offers significant improvement over OFDM in high mobility MIMO channels.

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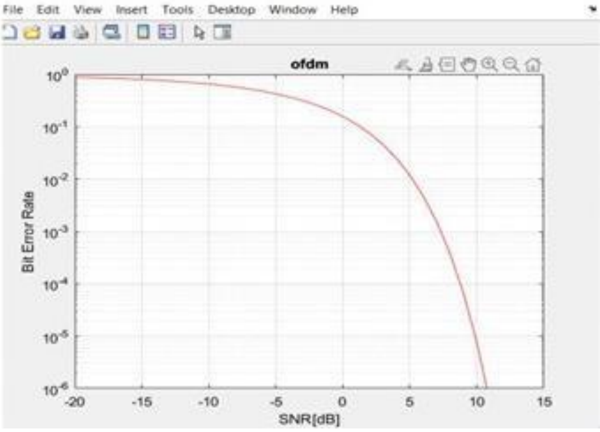

Figure 11 BER performance - OFDM

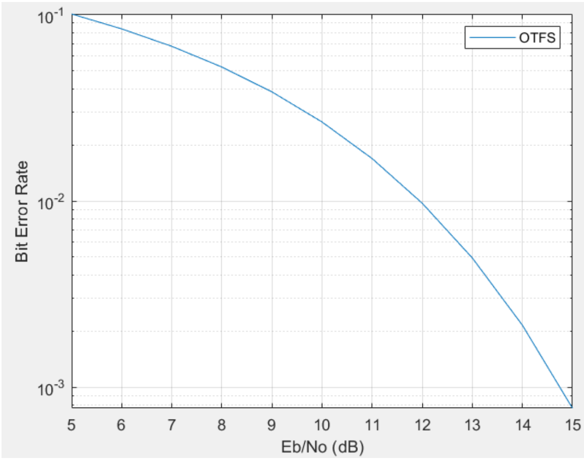

Figure 12 BER performance – OTFS

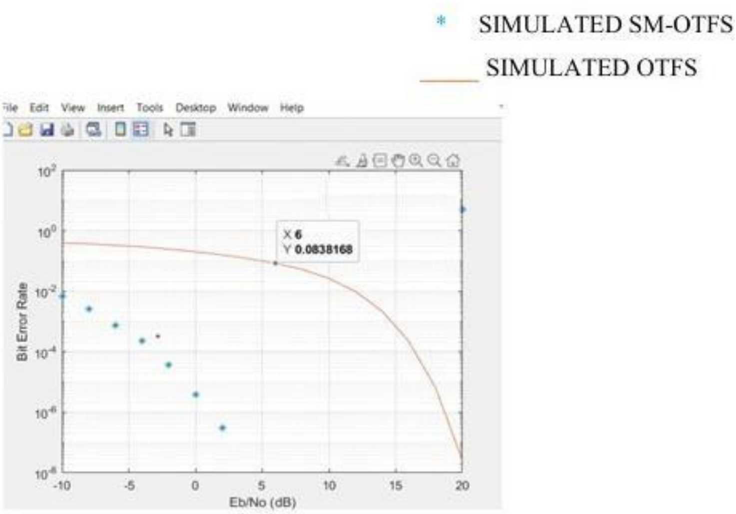

Fig 13 Comparison of BER performance of OTFS and SMOTFS

The BER performance of SISO-OTFS, and SM-OTFS with the MMSE detector for 16, 64-QAM symbols are obtained.

- In OTFS , at -10 dB SNR , the BER obtained approximately at 10^-1
- In SM-OTFS, at -10 dB SNR, the BER obtained approximately at 10^-2

While comparing the three different modulation such as OFDM, OTFS and SM-OTFS, the spatial modulation based OTFS has achieved high spectral efficiency where the BER is attained for the low SNR.

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CONCLUSION

As the SM-OTFS system by the joint design of SM and OTFS modulation is simulated. The system can achieve improved spectral efficiency and enhanced transmission reliability of the OTFS system. With perfect channel estimation, the closed-form expressions of both SNR and BER of the proposed SM-OTFS system has been derived. The complexity of the SM-OTFS system has also been evaluated in comparison with that of the OFDM and OTFS system. The SM-OTFS system can achieve much better BER performance than the typical OFDM and OTFS system for high mobility communications while maintaining the acceptable system complexity.

Future work will focus on investigate the practical implementation aspects of the proposed SM-OTFS system, considering hardware constraints, power consumption, and real-world deployment scenarios. Explore the integration of machine learning techniques for improved detection in the SM-OTFS system, considering adaptive algorithms and learning from dynamic channel conditions. Investigate the robustness of the SM-OTFS system in the presence of various impairments and potential security vulnerabilities. Develop methods to enhance system robustness and security.

REFERENCES

[1]. S. Saju, S. Priyadharsini, A. Sriram, “Review of 6G Communication in Haptic Technology”, Research India Publications, Volume 17, Number 1, (2022) pp. 243-252
[2]. Stefano Buzzi, Giulio Colavolpe, Tommaso Foggi, “LEOSatellite Diversity in 6G Non-Terrestrial Networks: OFDM vs. OTFS”, IEEE communication letters, VOL. 27, NO. 11, Nov 2023
[3]. Sejal Bandekar, Reeta Singh, “6G TECHNOLOGY”, International Journal of Research Publication and Reviews, Vol 3, no 6, pp 4659-4661, June 2022
[4]. Zhengquan Zhang , Yuchen Wu Xianfu Lei ,Lei Lei , IEEE, Zheng Ma and Zhiqiang Wei, “Coordinated Multi-Satellite Transmission for OTFS-Based 6G LEO Satellite Communication Systems”, IEEE journal on selected areas in communication, VOL. 43, NO. 1, Jan 2025
[5]. Omer Mohammed Khodayer Al-Dulaimi, Aymen Mohammed Khodayer Al-Dulaimi, Maiduc Osiceanu Alexandra and Mohammed Khodayer Hassan Al-Dulaimi, “Strategy for Non-Orthogonal Multiple Access and Performance in 5Gand6GNetworks”, Sensors, VOL 23, NO 1705, Feb 2023.
[6]. Shamik Sengupta and Mainak Chatterjee, “Sequential and Concurrent Auction Mechanisms for Dynamic Spectrum Access”, Orlando, FL 32816
[7]. Charu Singh, Priya Chauhan, “A 6G Network: Future of Nations? Challenges in 6G Communications”, Journal of Propulsion Technology, VOL 44, NO 04, Dec 2023.
[8]. Yangli, Pranav Madadi, Yeqing Hu Daoud Burghal Jeongho Jeon, Joon Young Cho, Andres F. Molisch and Jianzhong Zhang, “Enhanced AI-Based CSI Prediction Solutions for Massive MIMO in 5G and 6G Systems”, IEEE Access, VOL 11, NO 117822, October 2023.
[9]. Ulf Gustavsson, Thomas Eriksson, Christoph Studer, Herbert Zirath, Franz Dielacher, Ricardo Correia, Daniel Belo and Christian Fager, “Implementation Challenges and Opportunities in Beyond-5G and 6G Communication”, IEEE Journal of Microwaves, VOL 1, NO. 1, JAN 2021
[10]. Thorsten Wild, Volker Braun and Harish Viswanathan, “Joint Design of Communication and Sensing for Beyond 5G and 6G Systems”, IEEE Access, VOL 9, NO 30845, Feb 2021
[11]. Srikanth Kamath, Somilya Anand, Suyash Buchke and Kaushikee Agnihotri, “A Review of Recent Developments in 6G Communications Systems”, Engineering proceedings journal, VOL 59, NO 167, Jan 2024.
[12]. Faiza Nawaz, Jawwad Ibrahim, Maida Junaid, Sabila Kousar, Tamseela Parveen, “A Review of Vision and Challenges of 6G Technology”, International Journal of Advanced Computer Science and Applications (IJACSA), Vol. 11, No. 2, Dec 2020.
[13]. Armed Tusha, Saud Althunibat, Mazen O. Hasna, Khalid Qaraqe and Hüseyin Arslan, “Exploiting User Diversity in OTFS Transmission for Beyond 5G Wireless Systems”, International Journal for Advanced Computer Science and Applications (IJACSA), VOL 11, NO 2, Jan 2020.
[14]. Fadila Berrahma, Khalida Ghanem and Hicham Bousbia-Salah, “A New Multi-user Spatial Modulation Scheme Combining STBC-OFDM and CDMA”, 7th IEEE Conference (ISPA 2022), May 2022.
[15]. Arman Farhang, Ahmad Rezazadeh Reyhani , Linda E. Doyle, and Behrouz Farhang-Boroujen, “Low Complexity Modem Structure for OFDM-Based Orthogonal Time Frequency Space Modulation”, IEEE wireless communications letters, VOL. 7, NO. 3, 2018.
[16]. R.Hadani, S. Rakib, et al., “Orthogonal time frequency space modulation” IEEE Wireless Communications and Networking Conference (WCNC), 2017.
[17]. Yue Xiao, Feng Yu, Xia Lei, Dongxiao He, Ping Yang, Wei Xiang,“Performance Analysis for the N-Continuous Pre-coded SM- OFDM System” IEEE transactions on vehicular technology, VOL67, NO. 1, 2018.

DOI: 10.17148/IJARCCE.2026.15727

[18]. Armed Tusha, Khalid Qaraqe, and Hüseyin Arslan, "Exploiting User Diversity in OTFS Transmission for Beyond 5G Wireless Systems" IEEE Wireless communication Letters, Vol: 11, 2022.

[19]. Zeping Sui, Hongming Zhang, Yu Xin, Tong Bao, Lie-Liang Yang"Low Complexity Detection of Spatial Modulation Aided OTFS in Doubly- Selective Channels", IEEE Transactions on Vehicular Technology Volume: 72, 2023.

[20]. P. Fan, J. Zhao, et al., "5g high mobility wireless communications Challenges and solutions," China Communications, vol. 13, no. 2, 2016.

[21]. P. Raviteja, Y. Hong, et al., "Practical pulse-shaping waveforms for reduced- cyclic-prefix OTFS", IEEE Transactions on Vehicular Technology, vol. 68, no. 1,2018.

[22]. A. Rezazadeh Reyhani, A. Farhang, et al., "Analysis of discrete-time mimo ofdm-based orthogonal time frequency space modulation," in IEEE International Conference on Communications (ICC). IEEE, 2018.

[23]. W. Shen, L. Dai, et al., "Channel estimation for orthogonal time frequency space (OTFS) massive mimo", IEEE Transactions on Signal Processing, vol. 67, no. 16, 2019.

[24]. Yingchao Yang , Zhiquan Bai1, Ke Pan1 , et al., "Design and Analysis of Spatial Modulation Based Orthogonal Time Frequency Space System", IEEE Transactions on China communications Vol: 18, 2021.

[25]. Y. Zhao, Y. Xiao, et al., "Iterative compensation for clipping noise in spatial modulation OFDM systems," IEEE Transactions on Vehicular Technology, vol. 68, no. 12, 2019.