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Analysis of Orthogonal Time Frequency Space Modulation in Fading Channels

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Abstract- The ever-increasing demand for faster data rates and spectral efficiency has prompted further development of wireless communication systems. For their potential to improve the performance of wireless networks, orthogonal frequency division multiplexing (OFDM) and orthogonal time-frequency space modulation (OTFS) have drawn interest. The performance of OTFS and OFDM in both Rician and Rayleigh fading channels is the main subject of this research project's in-depth comparative investigation of the two technologies. In this paper, we examine the nuances of OTFS and OFDM, examining their merits and drawbacks in turn. We use complex simulation models to assess how well these methods work when faced with actual wireless channel circumstances. We specifically examine how well they can counteract the negative impacts of multipath fading, Doppler shifts, and signal-to-noise ratios (SNR) in both Rician and Rayleigh fading environments. The results of this study will give significant insight on the applicability of OTFS and OFDM for various wireless communication scenarios. We intend to provide help to communication engineers, network designers, and researchers in selecting the most suitable modulation and multiplexing techniques for their particular applications by comparing their performance in the presence of fading channels. Finally, our research makes a positive impact on the continuous development of wireless communication systems by opening the way for more effective and dependable wireless connectivity in a variety of fields, from 5G and beyond to burgeoning IoT and smart city applications.

Index Terms- OTFS, OFDM, Rician channel, Rayleigh channel

I. INTRODUCTION

The choice of modulation and multiplexing methods is essential in the never-ending search for quicker and more dependable wireless communication systems. Among the available options, orthogonal frequency division multiplexing (OFDM) and orthogonal time frequency space modulation (OTFSM) have come out to be two of the most competitive. These techniques provide the basis for multiple modern wireless communication systems, each of which has its own benefits and drawbacks. However, how well signals perform can be significantly affected by the properties of the medium of communication that they traverse over.

Wireless channels are inherently susceptible to fading due to signal reflections, diffraction, and scattering in the propagation medium. Two well-known fading models, Rician and Rayleigh channels, illustrate scenarios where signals are subject to varying degrees of multipath interference and attenuation. When creating communication systems that can deliver high data rates and dependability in a range of deployment circumstances, it is essential to understand how OTFSM and OFDM perform in these challenging channel conditions.

To determine the benefits and drawbacks of OTFSM and OFDM under the testing conditions of Rician and Rayleigh fading channels, this study conducts a thorough comparison analysis. In doing so, we seek to disseminate insightful knowledge that will advance wireless communication theory and provide engineers and researchers with helpful guidance as they work to improve communication systems for real-world applications. The parts that follow go into great length on the theoretical underpinnings, objectives, method, and anticipated outcomes of this important investigation.

II. LITERATURE SURVEY

In [1], an innovative two-dimensional modulation technology known as Orthogonal Time Frequency Space (OTFS) was developed for wireless communication applications. This cutting-edge modulation system exhibits superior performance in comparison to alternative modulation techniques. To harness the complete spectrum of channel diversity, the researchers strategically combined OTFS with a normalization process. Observations revealed that this integration results in uniform channel gain across all modulated symbols, indicating

Noteworthy advancement in wireless communication technology.

This analysis delves into critical downlink attributes, such as user multiplexing, adaptive modulation, and the support for an extensive array of antennas across a fading Multiple-Input Multiple-Output (MIMO) channel[2]. The system's speed, specifically for MIMO 4x4, remains consistent across various modulation modes, encompassing Quadrature Phase Shift Keying (QPSK) using Orthogonal Frequency Division Multiplexing (OFDM) in the transmission segment and 16QAM, 64QAM, and beyond. Nevertheless, notable distinctions in bit error rates (BER) were observed among these modulation types—QPSK, 4x4, and EPA 0Hz. The indication is that achieving a high downlink speed hinges on reducing the BER value. The analysis demonstrated discernible differences in the BERs associated with each modulation approach. This insight becomes particularly pertinent in the context of future wireless communications dominated by emerging technologies like 5G, where the strategic reduction of BER is expected to play a pivotal role in optimizing communication performance and reliability.

In [3], A recently uncovered technology named Orthogonal Time Frequency Space (OTFS) modulation holds promise for addressing challenges in the realms of 5G and 6G technologies. A comparative analysis was conducted to assess the performance of OTFS and Orthogonal Frequency Division Multiplexing (OFDM) concerning digital modulation formats, specifically employing the 16-QAM technique. The evaluation focused on the trade-off between Bit Error Rate (BER) and Signal-to-Noise Ratio (SNR), providing insights into the potential benefits of OTFS modulation in enhancing communication reliability and efficiency in advanced wireless networks.

In [4], findings highlight the versatile nature of OTFS, manifesting both Orthogonal Frequency Division Multiplexing (OFDM) and Single Carrier Frequency Division Multiple Access (SC-FDMA) characteristics, as evidenced by the matrix representation of the received OTFS signal. Furthermore, OTFS is capable of achieving comprehensive diversity in both the frequency and time domains.

This is accomplished by combining multipath counts and Doppler shifts, contributing to the overall diversity order. In their investigation, the team simulated and compared Bit Error Rate (BER) performance, incorporating Line-of-Sight (LOS) and Non-Line-of-Sight (NLOS) channels, employing a range of Tap Delay Line (TDL) channel models. This comprehensive approach provides valuable insights into the robustness and adaptability of OTFS across various channel conditions, shedding light on its potential applications in diverse wireless communication scenarios.

III. SYSTEM MODEL

In this analysis, a set of Quadrature Amplitude Modulation (QAM) information symbols, represented by coordinates x[k,l], is subjected to the Inverse Symplectic Fourier Transform within the framework of a bi-orthogonal transmit and receive pulse system, and packet bursts. The ISFFT is employed to construct symbols, each of which is subsequently transformed into the delay-Doppler domain. The signal x(t) is obtained by applying the Heisenberg transform to its output, which is represented as X(n,m).

Following transmission through a fading channel, the signal x(t) transforms into y(t). The signal y(t) is then analyzed Wigner transform, a valuable tool in signal processing, is utilized to analyze non-stationary signals and discern their frequency components as they evolve. Its applications extend to communication systems, radar, sonar, and other domains, offering a high-resolution time-frequency representation of signals.

Subsequently, the signal y(n,m) undergoes analysis using the Symplectic Finite Fourier Transform (SFFT), producing a map of the Delay-Doppler domain denoted as Y(n,m). The SFFT, analogous to a discrete Fourier transform (DFT), operates on a two-dimensional matrix of time-frequency symbols. This intricate process showcases the sophisticated signal processing techniques involved in extracting meaningful information from signals, offering applications in diverse fields such as communication systems, radar, and sonar.

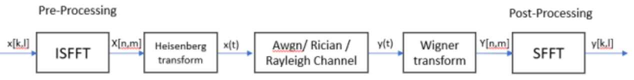

Fig 1 Block Diagram

IV. OTFS MODULATION

Let's explore OTFS modulation, where N represents the number of symbols with a symbol time of T, and M is the count of subcarriers with subcarrier bandwidth denoted as f. The overall bandwidth, B, is given by M Δf, and the total time, Tf, is calculated as NT. Additionally, in cases of critical sampling, the OTFS approach is effective when TΔf = 1. Employing Quadrature Amplitude Modulation (QAM), the data symbols x(k,l) are modulated on the NxM array within the Doppler delay range. This modulation is expressed using the inverse Symplectic Fourier transform (ISFFT) on an N × M grid.

$$(n\,,m\,)=\frac{1}{NM}\sum_{k=0}^{N-1}\ \sum_{m=0}^{M-1}\ (k\,,)e^{\,j2\pi(\frac{nk}{N}-\frac{ml}{M})} \quad (1)$$

After using the Heisenberg transform, X(n, m) is converted to x(t) as,

$$(t) = \sum_{k=0}^{N-1} \sum_{m=0}^{M-1} (n, m)_{tx}(t - nT) e^{j2\pi m \Delta f (t-nT)} \quad (2)$$

where $g_{tx}(t)$ is the transmitter pulse. In the delay-Doppler region h(,v), where and are the delay and Doppler, respectively, we have a channel with a response. Consequently, the time domain received signal y(t) on the receiver is transformed from the broadcast signal x(t) on the specified channel in the following way:

$$(t) = \iint (\tau, \nu)\, x(t - \tau) e^{j2\pi\nu(t-\tau)} d\tau\, d\nu \quad (3)$$

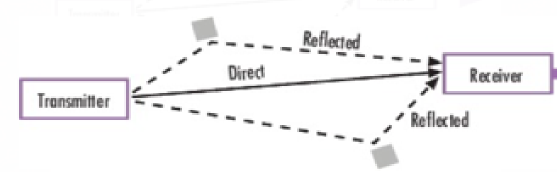

Fig-2 High mobility channels

The figure above shows the direct path and considerable mirrored path linking a stationary radio emitter and a moving receiver. The black outlines show reflectors, such as towers.

The main paths are what delay the signal's entry at the receiver. The radio wave experiences localized dispersion on each major path. Reflections from objects in the immediate vicinity typically produce this local dispersion. Multipath fading is the phenomena that happens when these opposing pulls collide at the receiver. Every major path acts as a distinct fading path as an outcome of this phenomenon.

1. Rician Fading Channel

A LOS component causes a non-zero mean received signal. In this instance, the Rician distribution describes the signal envelope, with the K factor determining the relative strength of the LOS component:

$$\mathrm{pz}(z) = \frac{z}{\sigma 2} \exp\left[\frac{-(z\,2 + s\,2)}{2\sigma 2}\right] \quad I_0(zs/\sigma^2),\ z \geq 0.$$

The average received power in the Rician fading is Pr = R

$$\int_0^\infty z^2 \mathrm{pz}(z) dz = s^2 + 2\sigma^2.$$

A fading parameter K, denoted by $K = s^2 / 2\sigma^2$ is commonly used to characterize the Rician distribution.

When expressed in terms of K, the distribution is:

$$\mathrm{pz}(z) = \frac{2z(K+1)}{Pr} \exp\left[-K - ((K+1)z^{2/} P_r)\right] \quad I_0\left(2 \sqrt{K(K+1)z / P_r}\right).$$

2. Rayleigh Fading Channel

When several objects in the surroundings refract radio signals before they reach the receiver, the notion of Rayleigh fading comes into play. The central limit theorem states that when there is enough dispersion, the channel's impulse reaction can be adequately described as a Gaussian process, despite its distribution of individual elements. If no single scatter component dominates, this Gaussian process will have an average of zero and an evenly split phase within 0 and 2 radians. As a result, the channel response envelope will display Rayleigh fading. When using a vertical receiving antenna with uniform sensitivity in all directions, this has been confirmed to be accurate for Rayleigh fading.

$$S(v) = \frac{1}{\pi f_d \sqrt{1 - \left(\frac{v}{f_d}\right)^2}}$$

V. SIMULATION RESULTS

In Rician Channel, if the signal is modulated using OFDM then the BER is decreasing with a steady slope as SNR is increasing. But if it is modulated using OTFS modulation then even though the BER rate is p

In Rayleigh Channel, the signals that are modulated using OTFS is showing slightly lesser BER than OFDM modulated signals.

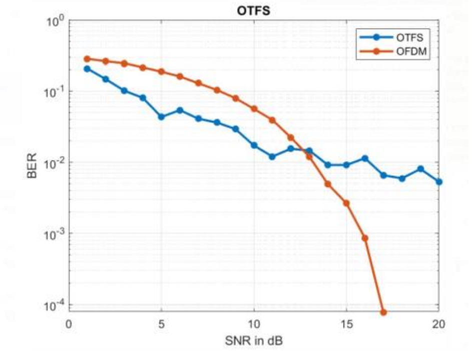

Fig-3 BER VS Snr Analysis of Otfs and Ofdm in Awgn Channel

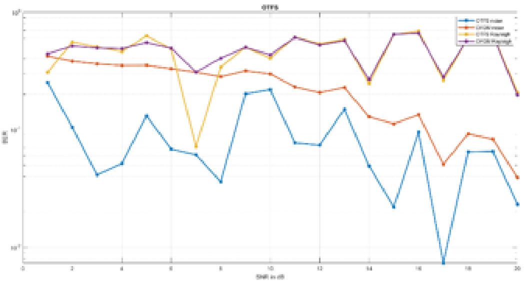

Fig-4 BER VS Snr Analysis of Otfs and Ofdm in Rician and Rayleigh Channel

VI. CONCLUSION

In the paper, the performance of OTFS and OFDM are evaluated. From this analysis, it is observed that OTFS outperforms OFDM. The graph shows that the BER rates of the signal broadcast using OTFS modulation are lower than those of the signal transmitted using conventional OFDM as the SNR increases. We can therefore draw the conclusion that in high mobility channels, OTFS modulation is superior to OFDM.

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