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Comparative BER Analysis of 5G and Beyond-5G Modulations for High-Speed Vehicular Communication

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Abstract:- The orthogonal time-frequency-space modulation technique proves to be a promising modulation scheme for beyond-5G communication systems. Its notable advantage lies in achieving a low bit error rate in the delay Doppler region, which is a significant improvement over traditional 5G OFDM systems that are prone to problems such as high BER and multipath fading. Our research focuses on modeling BER for OFDM and OTFS with the aim of conducting a comprehensive comparison of their performance. Our results show that OTFS consistently exhibits reduced BER in contrast to standard OFDM systems. This shows the potential of OTFS for more reliable communications, especially in scenarios where traditional OFDM systems encounter challenges related to errors and fading effects. This paper summarizes our efforts to highlight the benefits of adopting OTFS modulation for the development of robust and efficient communication systems in the future.

Keywords:- *Bit Error Rate (BER), Multipath-Fading, Delay Doppler Domain, OTFS, OFDM.*

I. INTRODUCTION

In our ever-evolving digital landscape, the demand for faster, more reliable, and ultra-low-latency wireless communication has reached a crescendo. As we stand on the cusp of the next generation of wireless technology, the advent of 6G promises to usher in a new era of connectivity that will transform industries, societies, and individual experiences. The project, "Performance Evaluation of 6G Wireless Communication Systems," embarkson a journey to explore, assess and decipher the profound implications of 6G technology.

A. The Evolution of Wireless Communication

To appreciate the significance of 6G, we must first trace the trajectory of wireless communication. From the humble beginnings of 1G, which marked the inception of cellular networks, to the lightning-fast speeds of 4G that gave birth to the mobile internet, each generation has pushed the boundaries of what's possible. 5G, the current pinnacle, has introduced us to enhanced mobile broadband, massive IoT connectivity, and mission-critical applications. However, as we set our sights on the not-so-distant future, the limitations of 5G are becoming increasingly apparent.

B. The Need for Beyond 5G

The hunger for data is insatiable, fueled by emerging technologies such as augmented reality, virtual reality, autonomous vehicles, and the Internet of Things. With 5G's network capacity approaching its limits, 6G emerges as the solution to satiate this data thirst. It promises to deliver unprecedented speeds, potentially reaching terabits per second, and latency so low it's nearly imperceptible, opening doors to applications once deemed fantastical.

C. Key Objectives

The primary aim of this project is to rigorously evaluate the performance of 6G wireless communication systems across a spectrum of scenarios and parameters. Through detailed simulations, real-world testing, and data-driven analyses, we seek to unravel the true capabilities of 6G networks. Key metrics under scrutiny include data throughput, latency, and reliability.

D. Beyond Theory

This endeavor goes beyond theoretical exploration. It encompasses practical implementation, addressing the hardware, software, and infrastructure prerequisites for 6G's successful deployment. By comparing 6G with its predecessors, we endeavor to elucidate its potential to revolutionize vital sectors like healthcare, smart cities, education, and entertainment.

II. LITERATURE SURVEY

The landscape of wireless communication has witnessed significant advancements, with modulation techniques playing a pivotal role in ensuring reliable and efficient data transmission. A comparative analysis of Bit Error Rate (BER) between Orthogonal Time Frequency Space modulation and Orthogonal Frequency Division Multiplexing reveals a rich body of literature addressing the challenges and strengths of these two approaches.

The introduction of OTFS as a modulation technique stems from the need to address the limitations encountered by traditional OFDM systems, especially in scenarios such as high-speed vehicular communication. Previous studies [1] have emphasized the susceptibility of OFDM to inter-carrier interference, a challenge intensified by Doppler spreading in dynamic environments.

Fred Wiffen et al. [1] conducted an extensive investigation that contrasts Orthogonal Time Frequency Space and Orthogonal Frequency Division Multiplexing within mmWave Line-of-Sight Mobility Channels. Their research delves into the unique challenges introduced by mobility channels, exploring how OTFS emerges as a prospective solution. This study not only lays a theoretical groundwork but also offers practical insights by empirically assessing and comparing the performance of these modulation schemes.Researchers recognize the increasing importance of dealing with synchronization errors and spectral efficiency problems in communication systems. The OTFS modulation, proposed by Ronny Hadani et al. [3], is presented as a cutting-edge modulation method designed to tackle the challenges posed by emerging 5G networks. This study highlights the technical aspects where OTFS outperforms the traditional Orthogonal Frequency Division Multiplexing, emphasizing its ability to adapt to different channel conditions and its superior handling of timing errors.

Additionally, Mustafa Ergen [4] in "Mobile Broadband: including WiMAX and LTE" and Suvra Sekhar Das et al. [6] in "OTFS: Orthogonal Time Frequency Space Modulation A Waveform for 6G Series" provide valuable insights into the broader context of mobile broadband technologies and the role of OTFS in the prospective 6G landscape, respectively.

The literature survey reinforces the significance of exploring advanced modulation techniques like OTFS to overcome the challenges faced by conventional methods such as OFDM. The studies cited lay the groundwork for the present research, underscoring the need for a nuanced understanding of the advantages and limitations of each modulation scheme.

III. METHODOLOGY

A. OTFS Modulation

Consider the following scenario in the context of OTFS modulation: Q indicates the number of subcarriers, each with a bandwidth of f. The product of M and Δf yields the overall bandwidth (B). Furthermore, if P represents the number of symbols and T represents the duration of each symbol, the total duration (Tf) can be determined as NT. TΔf= 1, signifying a key sample case, is an important requirement for the OTFS approach.

According to publications [1, 2, 6], Quadrature Amplitude Modulation (QAM) is used to modulate data symbols represented by x(k, l). These symbols are strategically coordinated within the Doppler delay range and are organized on a PxQ array. This coordination is depicted graphically on a PQ grid, designated as X(p, q), located in the time-frequency interval. The ISSFT is used to achieve the representation. According to the sources provided, this transformation process is critical in determining the organization and modulation of data symbols within the OTFS modulation technique.

$$\mathrm{X[p,q]}= \frac{1}{QP}\sum_{k=0}^{P-1}\sum_{l=0}^{Q-1} x\,[k,l]e^{j2\pi\left(\frac{pk}{P}-\frac{ql}{Q}\right)}$$

Following that, the signal X(p, q)x(t) is transformed using the Heisenberg transform, as detailed below:

$$x(\mathrm{t})= \sum_{p=0}^{P-1}\sum_{q=0}^{Q-1} X\,[p,q]g_{tx}(t-pT)e^{j2\pi q\Delta f(t-pT)}$$

In simpler terms, the signal x(t) is transmitted using a pulse $gtx(t)$, with Δf representing the subcarrier spacing and T as the symbol duration. As the signal travels through the delay-Doppler channel, characterized by h(τ,v) where τ is the delay and v is the Doppler, it undergoes a transformation. This transformation results in a received signal in the time domain, referred to as y(t), at the receiver. The process can be described as follows:

$$y(t)= \iint h(\tau,v)\,x(t-\tau)e^{j2\pi v(t-\tau)}\,d\tau\,dv$$

Upon applying the Wigner transform to the signal y(t), we observe a signal within the interval TF, and it is expressed as follows:

$$Y(\mathrm{n,m})=A_{g\,x,y}(t,f)|t=nT, F=m\Delta f$$

If we denote the received pulse as $grx(t)$, and the bi-orthogonality condition between $grx(t)$ and $gtx(t)$ is satisfied [2], the ensuing equation succinctly captures the input-output relationship within the transfer function (TF) range:

$$Y[p,q]=H[p,q]X[p,q]+V[p,q]$$

In this context, V(p, q) represents the noise in the time-frequency domain (TF) and H(p, q) is given by:

$$H[p,q]=\iint h(\tau,v)e^{j2\pi vpT}e^{-2j\pi(v+q\Delta f)\tau}\,dv\,d\tau$$

In addition with the (SFFT), the representation Y(p, q) is translated onto a diagram of the Delay-Doppler domain signal y(k, l). This mapping establishes the following relationship:

$$y[k,l]=\sum_{p=0}^{P-1}\sum_{q=0}^{Q-1} Y\,[p,q]e^{-j2\pi\left(\frac{pk}{P}-\frac{ql}{Q}\right)}$$

Beginning with equations (1) to (7), the input-output equation is expressed as follows [2]:

$$y(k,l)=e^{x}=\frac{1}{PQ}\sum_{l'=0}^{P-1} x(k',l')h_w\left(\frac{k-k'}{PT},\frac{l-l'}{Q\Delta f}\right)\ +\ v(k,l)$$

In the context provided, $hw(v,\tau)$ denotes the circular convolution of the channel response with a windowing function $w(v,\tau)$, and

$$h_w\left(\frac{k-k'}{PT},\frac{l-l'}{Q\Delta f}\right) = h_w(\nu,\tau)|\nu = \frac{k-k'}{PT},\tau = \frac{l-l'}{Q\Delta f}$$

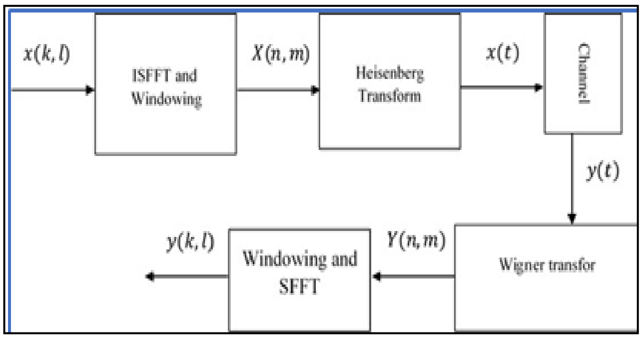

Fig. 1: OTFS Modulation

B. OFDM Modulation

Consider the block diagram of OFDM modulation Scheme

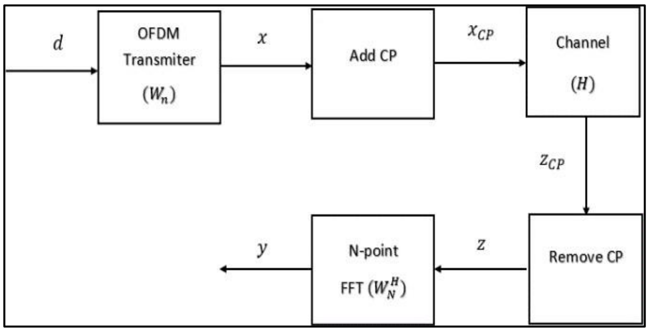

Fig. 2: OFDM Modulation Scheme

OFDM is a commonly used digital modulation technique in modern communication systems, particularly in wireless communication protocols such as Wi-Fi, LTE, and digital television broadcasting. OFDM modulation divides the available frequency spectrum into numerous orthogonal subcarriers, each of which carries a portion of the data. A simple block diagram of an OFDM system is shown below:

- Source of Information: The data to be transferred comes from a data source. This could be in the form of voice, video, or data.
- Channel Encoding: Prior to modulation, data is often channel encoded to offer redundancy and error-correction capabilities. This aids in the reduction of the impact of channel-induced mistakes.
- Conversion from Serial to Parallel: After that, the encoded data is changed from a serial bit stream to parallel data streams. Because OFDM operates on several parallel carriers, this is required.
- Subcarrier Mapping: The parallel data streams are then assigned to specific subcarriers. OFDM employs a large number of orthogonally separated subcarriers, each carrying a portion of the data.
- IFFT Using an Inverse Fast Fourier Transform (IFFT), the data on the subcarriers is translated to the frequency domain from the time domain. The parallel data streams are converted into the time-domain OFDM symbol throughout this process.
- Addition of a Cyclic Prefix: A cyclic prefix is added to the OFDM symbol to reduce the impacts of multipath interference in wireless communication. This is accomplished by copying the end of the symbol and attaching it to the beginning, resulting in a guard interval.
- DAC (Digital-to-Analog Conversion): In the process of digital-to-analog conversion (DAC), the digital OFDM symbol undergoes transformation into an analog signal. The resulting analog signal represents the time-domain waveform of the OFDM symbol.
- RF Up-Conversion and Amplification: For transmission, the Analog signal is upconverted to radio frequency (RF) range. The signal is modulated onto a carrier frequency in this process. For efficient transmission, the signal can also be amplified.
- Channel: The modulated signal is conveyed via a communication channel, which can be either air (for wireless communication) or a wired media.
- RF Down-Conversion: At the receiving end, the received signal undergoes down-conversion, transitioning from the radio frequency (RF) to the baseband frequency.
- Analog-to-Digital Conversion: An Analog-to-digital converter is used to convert the down-converted signal back into the digital domain.
- Removal of Cyclic Prefixes: The received signal is devoid of the cyclic prefix.
- Fast Fourier Transform (FFT): The received time-domain OFDM symbol undergoes conversion from the time domain to the frequency domain through the application of a Fast Fourier Transform (FFT).
- Subcarrier De-mapping: Each subcarrier is de-mapped, and parallel data streams are extracted.
- Decoding of Channels: To retrieve the original information, error repair and decoding methods are used to the data.
- Data Sink: Decoded data is delivered to the destination or data sink for additional processing or use.

IV. SIMULATION RESULTS AND DISCUSSION

In this section, we will assess and compare the performance of OTFS and OFDM by evaluating their Bit Error Rates (BER), as depicted below.

A. OTFS Simulation Results

Figure 3 shows the simulated results for OTFS modulation that show the Bit Error Rate vs Signal-to-Noise Ratio performance. As seen in the graph, the BER is larger at lower SNR values and steadily reduces as the SNR increases.

Physically, this is predicted because the BER lowers as SNR increases. This is because, with a greater SNR, the signal power becomes more dominating in comparison to the noise power. In essence, an increase in the signal-to-noise ratio improves the dependability of the communication system, resulting in fewer bit mistakes.

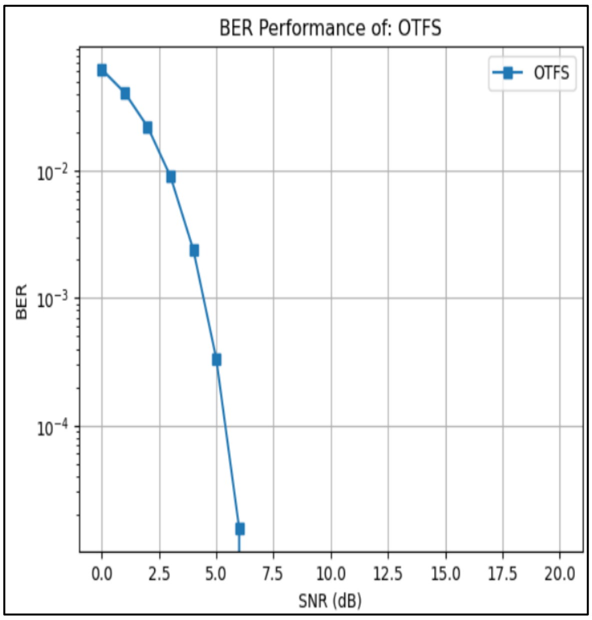

Fig. 3: OTFS BER vs SNR

B. *Simulation Results of OFDM*

Figure 4 illustrates the simulation outcomes for OFDM modulation, presenting the correlation between Bit Error Rate (BER) and Signal-to-Noise Ratio (SNR). The graph distinctly illustrates that as the SNR increases, the BER experiences a gradual decrease. Additionally, the variation in BER relative to SNR within the 0 to 8 dB range is characterized by a gradual and nearly negligible trenddduring this interval.

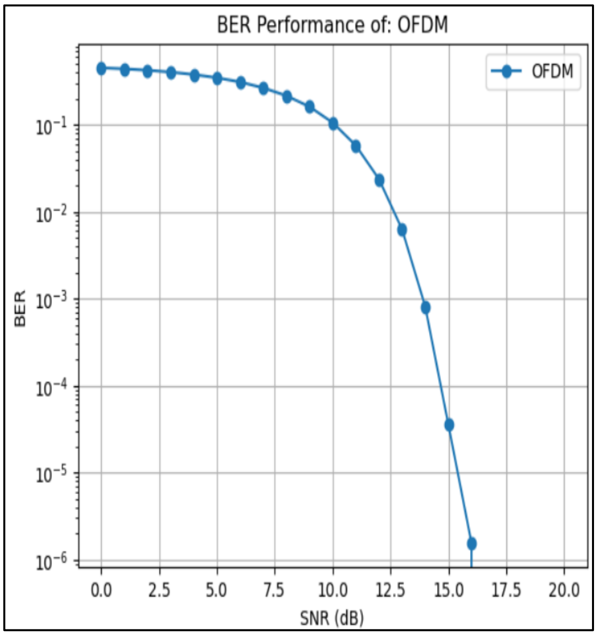

Fig. 4: OFDM BER vs SNR

C. *Comparision Results*

Figure 5 demonstrates the relationship between Bit Error Rate and Signal-to-Noise Ratio for both OTFS and OFDM. Notably, throughout the SNR range, OFDM Bit Error Rate is larger than Bit Error rate of OTFS. However, above 8 dB, a significant reversal occurs, with OTFS outperforming OFDMas SNR increases.

The above simulation results shows the BER (Bit Error Rate) Curves of OFDM vs OTFS. As we observe the both BER curves compared to OFDM, OTFS has Lower Bit Error Rate as SNR is increasing and we can say that OTFS is the better modulation technique compared to OFDM for its usage in Future 6G Wireless Communications Systems.

This discovery implies when signal-to-noise ratio rises, the performance improvement is small or non-existent. It stresses the efficacy of OTFS modulation, particularly in situations where greater SNR values are critical for improving communication dependability. In difficult signal situations, the comparison illustrates the superiority of OTFS over OFDM.

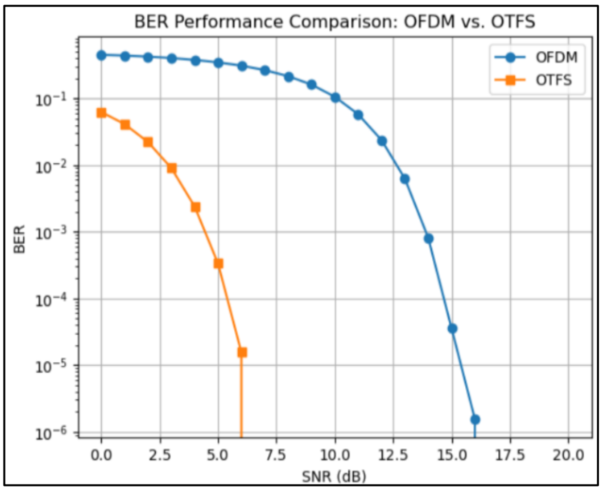

Fig. 5: BER Vs SNR for OFDM and OTFS

V. CONCLUSION

In summary, a comparison of OFDM and OTFS waveforms using numerical simulations comparing Bit Error Rate vs Signal-to-Noise Ratio indicates significant differences in performance. The results show that Orthogonal Time Frequency Space modulation surpasses Orthogonal Frequency Division Multiplexing in terms of dependability, which is especially noticeable at higher SNR values.

Based on these findings, OTFS appears as a preferred modulation option, outperforming OFDM in terms of communication performance. OTFS's potential goes beyond its existing benefits, establishing it as a good contender for solving the rising demands of future communication networks, particularly the projected requirements of 6G networks.

In the future, we suggest expanding the inquiry into the performance of OTFS modulation by investigating its compatibility with Non-Orthogonal Multiple Access (NOMA). Furthermore, investigating the combination of OTFS and Filter Bank Multi Carrier (FBMC) gives a viable option for future study. These future research will strive to increase our understanding of OTFS's capabilities and prospective advancements, while also providing significant insights into the progress of communication technology.

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