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5G-NR Based Physical Layer Techniques for High-Speed 6G NTN Connectivity

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Abstract:

The study investigates physical layer strategies rooted in 5G new radio (NR) to help much-speed connectivity and emerging 6G non-terrestrial network (NTNs). The use of MATLAB-based simulation. We examine the bit error rates of an performance of several modulation schemes data such as QPSK, 16 QAM, OTFS and, FBMC across diverse channel conditions such as AWGN, Raytleign and Rician fading. The analysis assumes ideal channel state information stands for (CSI) at the receiver. We compare traditional modulation formats (QPSK and 16 QAM) with more advanced alternatives of OTFS and FBMC to assess their resilience to noise and multipath effects. The results of the output show that OTFS and FBMC consistently outperformed conventional schemes. especially in dynamic feeding scenarios, offering lower BER and greater robustness. These insight highlight their suitability for integration into the future 6G NTN system. Where dependable and high throughout links are essential for seamless communication across space, air and ground domains.

Keywords: Bit Error Rate (BER) Performance, 5G new radio (NR), 6G non-terrestrial communication, OTFS signal processing, FBMC transmission schemes.

1. Introduction

The rapid evolution of wireless unmanned aerial vehicles (UAVs) is providing seamless coverage in remote and urban areas alike. Shift Keying (QPSK) and 16-Quadrature Frequency Space (OTFS) and Filter Bank Multicarrier channel and SNR conditions for NTN scenarios. Furthermore, most work focuses on either terrestrial high-speed mobility or simulation under idealised channels, leaving a research gap in evaluating BER performance comprehensively across AWGN, Rayleigh, and Rician fading channels within a single MATLAB-based framework. This study aims to fill this gap by comparing the BER performance of these four modulation schemes under realistic channel conditions, evaluating the robustness of advanced waveforms for high-mobility and NTN scenarios, and providing practical insights for physical layer design in 6G NTNs, supporting ultra-reliable and high-speed communications.

The communication technology from 4G LTE to 5G new radio has dramatically improved data rates, reliability and demand for high-speed, ubiquitous connectivity and including autonomous emerging application vehicles, remote sensing and global internet coverage, has necessitated research into 6G. The non-terrestrial network (NTNs) integrates terrestrial networks with satellites of high altitude platforms of HAPs.

The propagation environment in NTNs is highly dynamic and involves challenges such as multipath fading, Doppler effects and line of sight variability, which all directly impact physical layer performance. Conventional modulation schemes, quadrature phase, amplitude modulations of 16 QAM, are widely using in 5G systems due to their simplicity and spectral efficiency. While they perform well at the additive while Gaussian noise AWGN channel and their robustness decreases significantly in fading environments. These are common in NTNs' advanced waveforms, including orthogonal time techniques.

FBMC has been proposed to address these challenges. The OTFS maps data symbol in the delay Doppler shifts, while FBMC. To improve the efficiency of the spectral by pulse shaping and reduce intersymbol interference. Several works have considered the suitability of advanced modulation schemes for high mobility and non-terrestrial environments. To analyse waveform and numerology options for 5G-NR, highlighting the limitations of traditional OFDM under high Doppler conditions and the potential for spectral efficiency by using FBMC improvements. The presence of OTFS is a robust modulation technique for time-varying channels, demonstrating better BER performance compared with OFDM in high-speed vehicular scenarios. The conducted comprehensive performance analysis of OTFS was conducted over fading channels and showing superior delay doppler diversity gains in Rayleigh and Rician environments. The comparison of OFDM and FBMC emphasises the reduction of band emissions and improved spectral containment of FBMC. The survey on the integration of NTNs with 5G. The networking identifies the physical layer challenge, including channel impairments, Doppler shifts and BER degradation. The discussed architecture and requirements of 6G network underline the need for robust modulation and waveform design to support ultra reliable low and latency communication in NTNs. The underlined and the impact of fading on conventional QAM and QPSK systems further reinforce the need for advanced modulation schemes for NTN deployments. A suitable study of an OTFS-based multiple access for high mobility networks, confirming its robustness against channel variations and better BER performance. The comparison of FBMC and OFDM in 5G and beyond networks demonstrates FBMC's robustness under multipath fading. The proposed model of OTFS-aided MIMO system exploits delay-doppler diversity, showing significant

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performance gains over the conventional modulation in high mobility scenarios.

While existing research has shown the advantages of OTFS and FBMC over conventional QAM-based systems of few studies have provided a unique unified comparison of QPSK, 16 QAM, OTFS and FBMC under the same conditions.

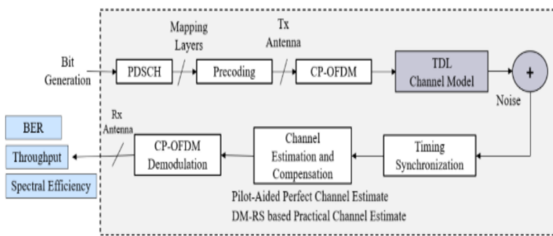

Figure 1: 5G-NR Physical Layer model

3. Proposed System

The PDSCH is the main 5G NR downlink channel, transmitting user data, system information, paging data, and higher-layer data signals to all connected devices. In link-level simulations, data is generated, LDPC-encoded, MIMO-precoded, modulated, passed through TDL channels with noise, then demodulated and decoded to measure BER, throughput, and spectral fast efficiency.

In a modulation schemes include QPSK and 16/64/256-QAM. While the LDPC coding model represents realistic propagation with single-path Rayleigh and Rician fadings. The large mobility scenarios up to 500 kms are addressed in the paper. The analysis effects due to numerology, modulation and coding schemes, MIMO and beamforming and perfect versus DM-RS based on channel estimations.

In a proposed method evaluates the BER performances of QPSK, 16QAM, OTFS, and FBMC under AWGN, Rayleigh, and Rician channels. Random data symbols are generated and modulated according to each scheme. QPSK and 16QAM use standard QAM modulation, OTFS maps symbols in the delay-Doppler domain, and FBMC applies a prototype filter to reduce interference. The transmitted signal is normalised to keep the power consistent across schemes.

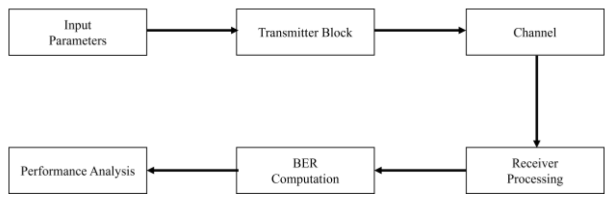

Figure 2: Flow Diagram of Proposed Methodology

Random data symbols d[n]d[n]d[n] are generated and modulated: for QPSK and 16QAM, standard QAM modulation is used:

$$x[n] = \mathrm{qammod}(d[n],M) \qquad ….(1)$$

QPSK (M=4) symbol mapping:

Input $d[n] = 2 \rightarrow x[n] = 1-jx[n]$

$= 1 - j$ (assuming Gray coding)

16QAM (M=16) symbol mapping:

Input $d[n] = 10 \rightarrow x[n]=1+3j$

For OTFS, symbols are mapped in the delay-Doppler domain using 2D transformations:

$$X=\mathrm{reshape}(d[n],N,M), x=\mathrm{ifft2}(X) \qquad ….(2)$$

- Suppose 4 symbols d = [0,1,2,3], reshape 2×2:

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$$X = \begin{matrix} 0 & 1 \\ 2 & 3 \end{matrix}$$

- Apply 2D IFFT:

$$X = \text{ifft2}(X) \approx \begin{matrix} 1.5 + oj & -0.5 + 0.5 \\ -0.5 - 0.5j & 0.5 + 0j \end{matrix}$$

- xxx is the transmitted OTFS signal.

For FBMC, a prototype filter p[n]is applied:

$$x[n] = d[n]*p[n] \quad \text{….(3)}$$

Input symbols: d[n] = [1,1, -1, -1]

Prototype filter: p[n] = [0.5,1,0.5]

x[0] = 1 x 0.5 = 0.5

x[1] = 1 x 1 + 1 x 0.5 = 1.5

x[2] = 1 x 0.5 + 1 x 1+ (-1) x 0.5 = 1

x[3] = 1 x 0 + 1 x 0.5 + (-1) x 1+ (-1) x 0.5

= -1

Resulting FBMC transmitted signal:

x[n] = [0.5, 1.5, 1, -1]

The transmitted signal passes through a channel h[n]with noise w[n]:

$$y[n] = h[n]\cdot x[n]+w[n] \quad \text{….(4)}$$

- Transmitted signal x[n]=1+j
- Channel h[n]=0.8+0.6j
- Noise w[n]=0.05−0.1j

y[n]=(0.8+0.6j) (1+j) + (0.05−0.1j)

Step 1: Multiply channel:

(0.8+0.6j) (1+j) = 0.8+0.8j+0.6j+0.6j2

=0.8+1.4j−0.6

=0.2+1.4j

Step 2: Add noise:

y[n]=0.2+1.4j+0.05−0.1j=0.25+1.3j

The received signal is equalized using perfect channel knowledge:

x^[n] = y[n] / h[n] ….(5)

X^[n]= 0.25+1.3j / 0.8+0.6j

Multiply numerator and denominator by conjugate of h[n]:

x^[n] = (0.25+1.3j) (0.8−0.6j) / 0.82+0.62

=1.13+0.86j / 1

≈1.13+0.86j

This is the **estimated transmitted symbol**.

Demodulation recovers d^[n] and BER is calculated as:

BER= Number of bit errors / Total bits transmitted

Suppose 1000 bits transmitted, 20 errors:

BER = 20 / 1000

BER = 0.02

In this 5G NR PDSCH simulation, random data symbols d[n]d[n]d[n] are first generated and modulated according to the chosen scheme: QPSK and 16QAM use standard QAM mapping, OTFS maps symbols in a 2D delay-Doppler grid followed by a 2D IFFT, and FBMC applies a prototype filter to reduce interference. The modulated symbols x[n] are transmitted through a wireless channel h[n] with added complex Gaussian noise w[n], representing AWGN or fading environments

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such as Rayleigh and Rician. At the receiver, perfect channel state information is assumed, allowing equalization via x^[n] = y[n] / h[n] to remove channel distortions. After equalisation, demodulation recovers the estimated symbols d^[n], which are compared with the transmitted data to compute the Bit Error Rate (BER). For example, if a transmitted QPSK symbol 1+j passes through a channel h[n]=0.8+0.6j with noise 0.05−0.1j, the received signal is y[n]=0.25+1.3j, and equalisation recovers x^[n]≈1.13+0.86j. The BER is then calculated as the ratio of incorrectly received bits to the total transmitted bits, providing a quantitative measure of the reliability of each modulation scheme under different SNR levels and channel conditions.

4. Results

Figure 2 shows a plot of the comparative performance of four modulation schemes, such as QPSK, 16 QAM, OTFS and FBMC, over three channel conditions, such as AWGN, Rayleigh and Rician, wherein the bit error rate stands for (BER) are plotted in the logarithmic y-axis against the signal-to-noise ratio in dB in the x-axis. In an AWGN channel and the BER for all schemes improves with an increase in SNR, and QPSK and OTFS exhibit the lowest error rate. The signifying that they are most resilient to noise. For Rayleigh fading, which model is used for severe multipath environments? The OTFS has superior performance to others by yielding lower BER across the considered SNR range. While 16 QAM and FBMC deteriorate more significantly, and since these methods are highly sensitive to channel variations. The performance under Rician fading and which encompasses both line of sight and scattered propagation paths, and better than under Rayleigh. Again, OTFS demonstrates superior robustness, followed by QPSK. The plot indeed reflects that OTFS is the most robust modulation technique under varying channel conditions. Hence, this makes OTFS highly suitable for high mobility and interference-prone communication environments. The QPSK can be promising in a low-complexity system.

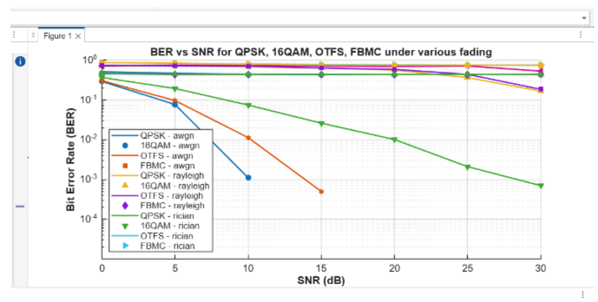

Figure 3: four modulation schemes—QPSK, 16QAM, OTFS, and FBMC

Noise Ratio (SNR) in decibels, ranging from 0 to 30 database, while the y-axis shows BER on a logarithmic scale from 10010^0 to 10−510^{-5}. Figure 3 below shows MATLAB and the simulation plot titled BER vs SNR for QPSK, 16 QAM, OTFS, FBMC under various fading comparing the bit error rate of BER performance of four modulation schemes of QPSK, 16QAM, OTFS and FBMC across the three channel conditions of AWGN, Rayleigh and Rician. The x-axis represents the signal to each curve in the plot corresponding to a unique combination of modulation and fading type, with markets and annotations highlighting specific BER values at given SNR points. The result shows that OTFS consistency records the lowest BER across. All fading conditions are especially under Rayleigh and Rician channels, respectively, exhibit their robustness in high mobility and multipath environments. The QPSK performs reliably under AWGN but degrades under fading, and 16 QAM exhibits higher BER at low SNR values owing to its sensitivity to noise. The FBMC offers moderate performance of balancing the spectral efficiency of resilience. Overall, the plot shows that OTFS is the most effective modulation scheme for keeping low error rates in diverse channel conditions. To make it suitable for next next-generation wireless communication system.

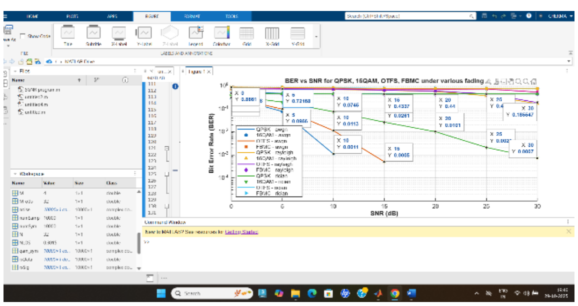

Figure 4: BER vs SNR for QPSK, 16QAM, OTFS, FBMC under various fading conditions

5. Conclusion

This study comprehensively analysed and compared the bit error rate stands for (BER) performance of four modulation schemes, such as QPSK, 16 QAM, OTFS and FBMC, under various channel conditions, including AWGN, Rayleigh and Rician fading channel. The simulations were performed using MATLAB with an emphasis on testing the strength, adaptability and efficiency of conventional waveform technique in the context of 6G non-Terrestrial network that, through traditional modulation techniques including QPSK and 16 QAM, perform well in noise-limited environments; their performance significantly deteriorates under fading and high mobility scenarios typical of NTNs. In contrast and the sophisticated typical of NTNs. In modulation schemes, OTFS and FBMC exhibit better robustness against Doppler shifts and multipath fading, and time variations. The OTFS in particular showed the lowest BER for fading channels owing to its capability to exploit delay-doppler diversity, which is highly suitable for high-speed satellite and aerial communication links. The FBMC, with its improved spectral containment and reduced inter-symbol interference, also showed considerable performance benefits over conventional OFDM-based methods.

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