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Performance Analysis and Comparison between OWDM (Orthogonal Wavelet Division Multiplex) and OFDM (Orthogonal Frequency Division Multiplex)

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Problem Statement

- The high Peak-to-Average Power Ratio (PAPR) of Filtered-Orthogonal Frequency Division Multiplexing (F-OFDM) leads to inefficiencies and performance issues in 5G and beyond wireless systems, necessitating the exploration of alternative multicarrier modulation techniques.

- This study proposes Filtered Orthogonal Wavelet Division Multiplexing (F-OWDM), utilizing wavelet transforms to replace Fourier transforms, aiming to eliminate the need for a cyclic prefix and to improve bandwidth efficiency while reducing PAPR and Bit Error Rate (BER) compared to conventional F-OFDM.

Current 5G Modulation Schemes

Quadrature Amplitude Modulation (QAM)

- QAM is a widely used modulation scheme in 5G for its efficiency in transmitting multiple bits per symbol.
- It modulates both the amplitude and phase of the carrier signal to represent digital data.
- Variants like 16-QAM, 64-QAM, and 256-QAM are commonly employed in 5G networks.

Orthogonal Frequency Division Multiplexing (OFDM)

- OFDM is a fundamental modulation scheme in 5G, especially for downlink transmissions.
- It divides the available frequency spectrum into orthogonal subcarriers, allowing for efficient data transmission.

Generalized Frequency Division Multiplexing (GFDM)

- GFDM is a flexible approach to subcarrier multiplexing, which allows for lower Out-of-Band (OOB) radiation and reduced interference. It's considered for scenarios that require high spectral efficiency and low latency.

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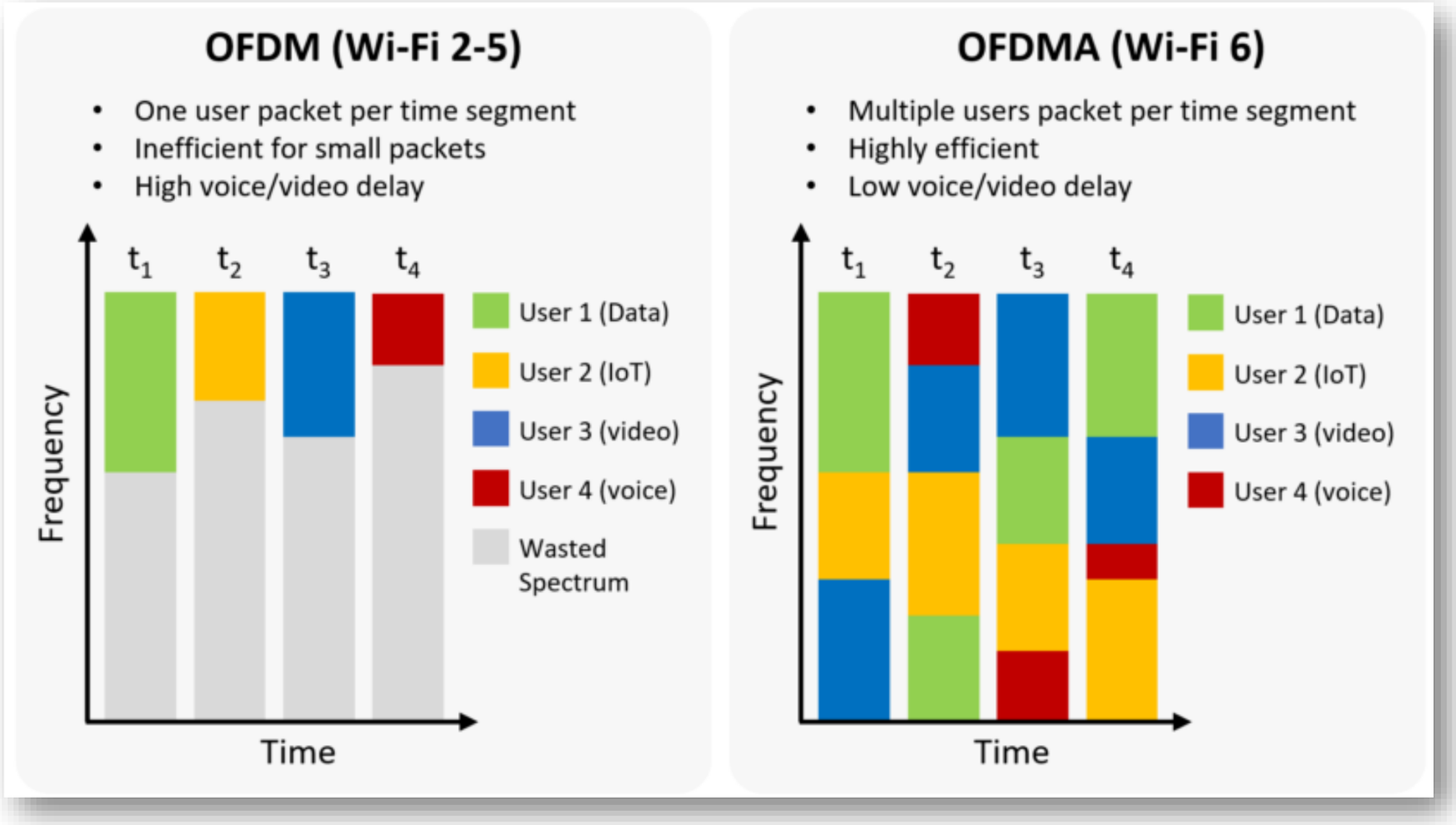
OFDM V/S OFDMA



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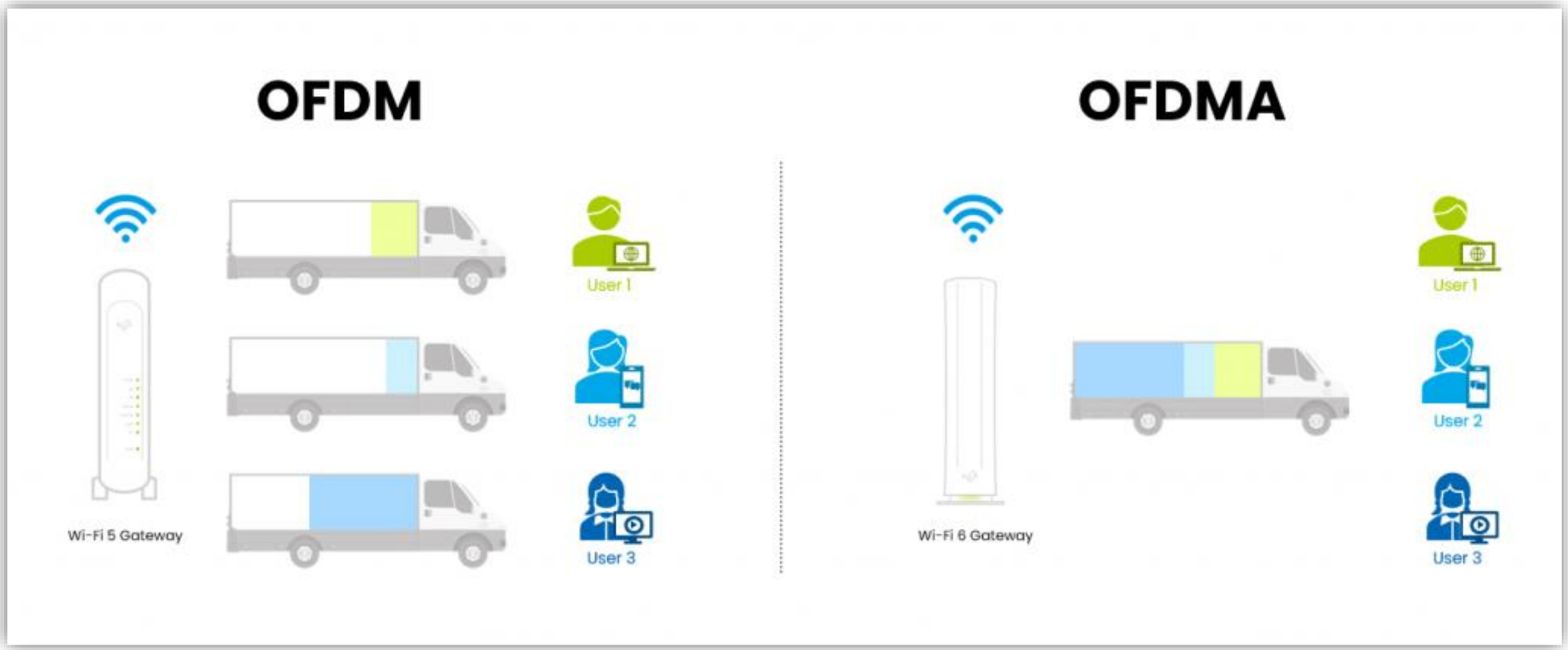
OFDM v/s OFDMA



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OFDM vs OWDM

OFDM

1. It possesses a high peak-to-average power ratio (PAPR), which results in its poor performance.
2. Low complexity.
3. Frequency and Time Offset: Frequency offset can lead to issues such as inter-carrier interference (ICI),
4. Cyclic Prefix is required.
5. Utilizes the FFT.

OWDM

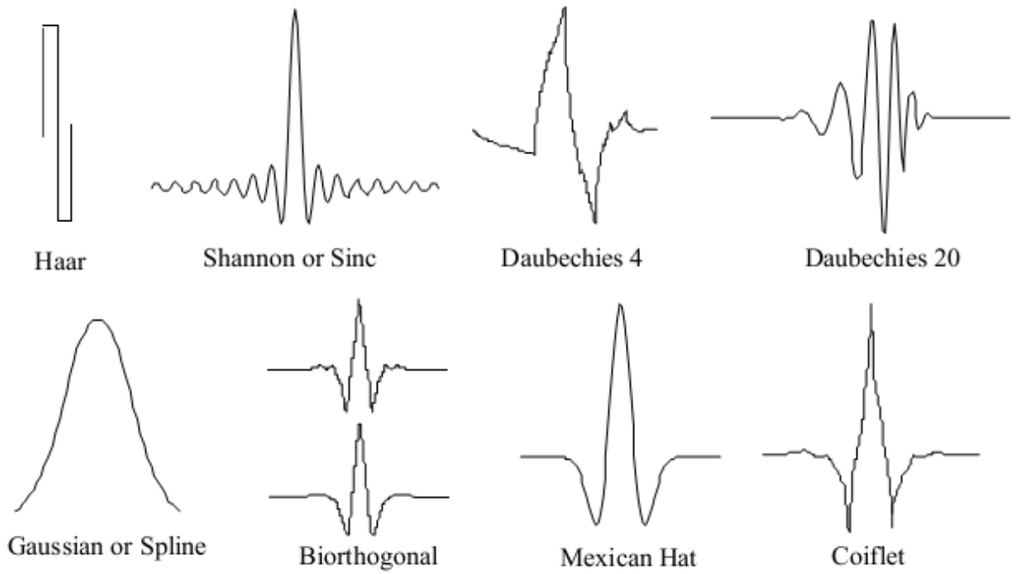
1. F-OWDM system does not require a cyclic prefix because of the overlapping sub-carriers in the time and frequency domains
2. Higher complexity
3. Utilizes filter-bank based wavelet transform

The Wavelet Transform

- Fourier Transform is the decomposition of a complex signal into sum of sine signals. The problem with Fourier Transform is that it gives no information about the time domain.
- Wavelet transforms give resolution in both time and frequency (multiresolution analysis)
- A wavelet is a short -lived oscillation localized in time. Wavelets in general is the family of all these different types. (Haar, Mexican Hat, Gaussian, Daubechies, Morlet etc.)
- For this analysis, we use **Discrete Wavelet Transforms**

Why Wavelets?

- Due to its overlapping sub-carriers in the time and frequency domains, cyclic prefix is not required -> **Higher BW efficiency**
- F-OWDM has the advantage of lower PAPR and lower BER than the C-F-OFDM system



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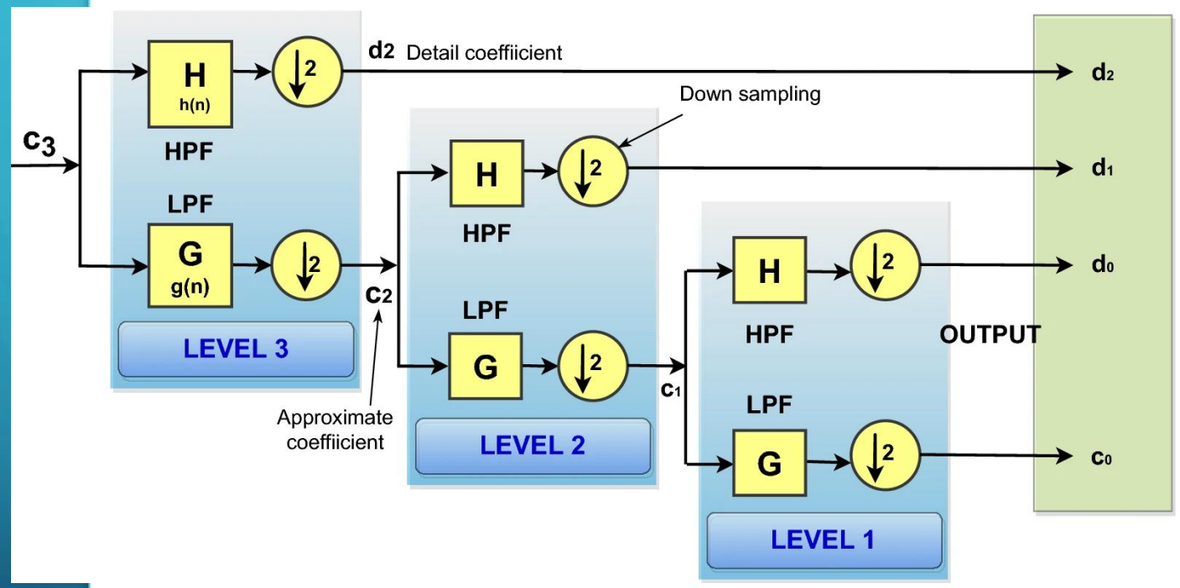
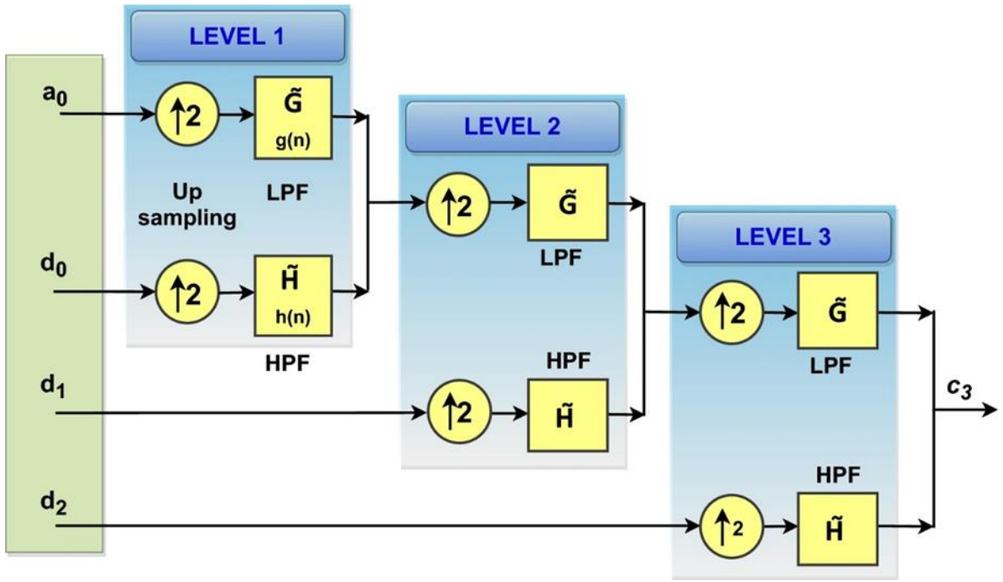
DWT & IDWT



Discrete Wavelet Transform



Inverse Discrete Wavelet Transform

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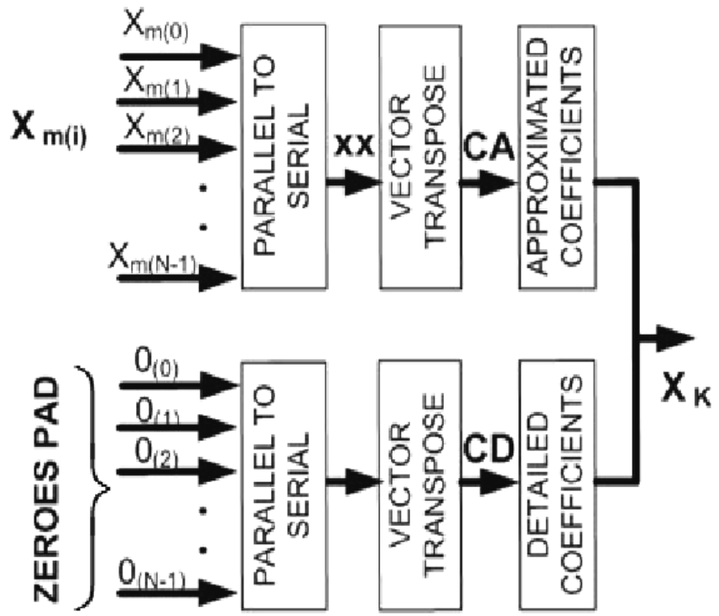
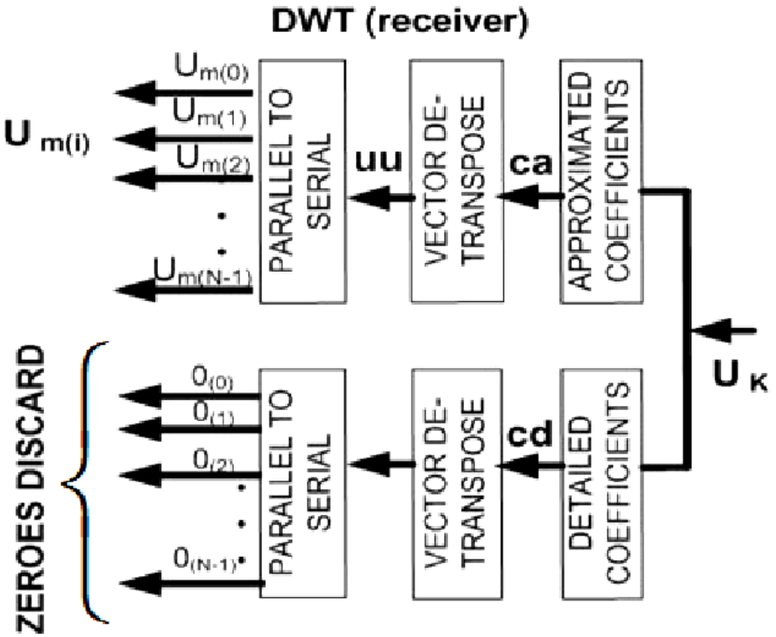
OWDM Transmitter and Receiver



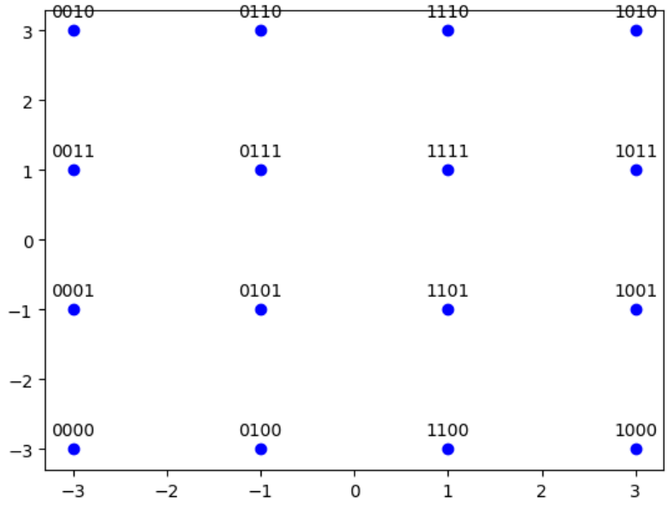
Transmitter IDWT

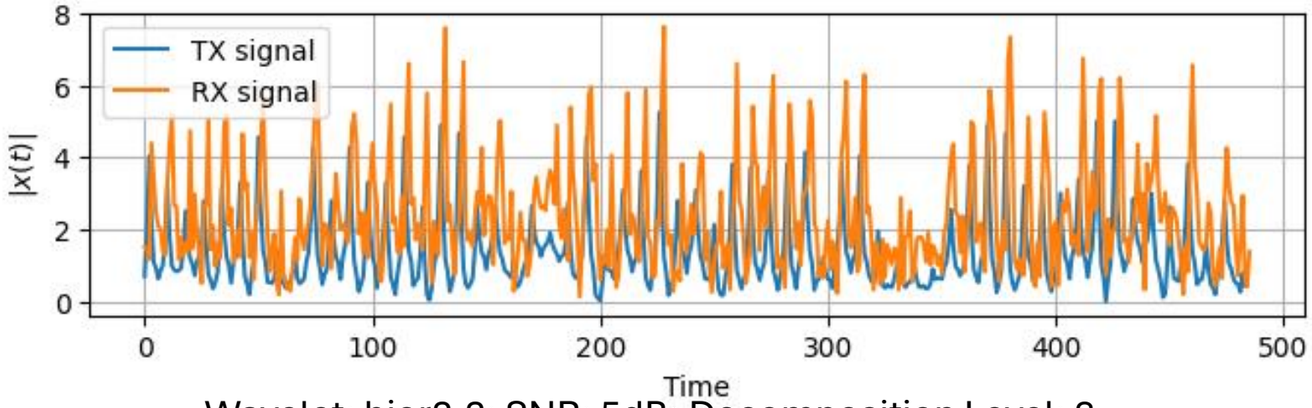


Receiver DWT

Experimental Setup & Implementation

- Data was generated using a binomial distribution in bits.
- 64 OWDM subcarriers (8 pilot carriers and 55 data carriers)
- 16QAM modulation with gray mapping
- Frequency selective channel: two-tap multipath channel -> $[1, 0, 3 + 3j]$ + noise (as defined by SNR)
- *Pywavelets* python package is used to apply multi-level discrete wavelet transform
- Transmitted signal is convolved with the channel response + noise
- Channel estimation is performed + Equalization
- Analyzed Performance





Wavelet: bior2.2; SNR: 5dB; Decomposition Level: 3

Cellular Network Generations

Wavelet Transform OFDM:

- Wavelet Transform OFDM is an alternative modulation technique that replaces Fourier transform with wavelet transform.
- Wavelet transform provides a more flexible time-frequency representation compared to Fourier transform.

Key Features:

- Wavelet OFDM enables efficient modulation of signals with varying bandwidth requirements and time-varying characteristics.
- It offers better support for non-stationary signals, making it suitable for dynamic wireless environments.

Benefits:

- Improved spectral efficiency: Wavelet OFDM allows for more efficient use of the available spectrum, accommodating higher data rates.
- Enhanced robustness: Wavelet OFDM exhibits resilience to channel distortions and noise, resulting in more reliable communication.

Integration with 5G:

- Wavelet OFDM technology can be integrated into 5G networks to enhance support for diverse applications and improve overall system performance.

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Performance Metrices

Power Spectral Density

- Power Spectral Density (PSD) represents the distribution of signal power across different frequencies.
- In F-OWDM, PSD indicates how the signal power is distributed over the frequency spectrum.

Peak-Average-Power Ratio

- Measures the ratio of the peak power to the average power of the transmitted signal.
- Lower PAPR indicates reduced signal distortion and improved power efficiency.

BER

- BER vs. SNR curve illustrates the relationship between the bit error rate (BER) and the signal-to-noise ratio (SNR) of the communication system.
- In F-OWDM, BER vs. SNR analysis quantifies the system's performance under varying levels of noise and interference.

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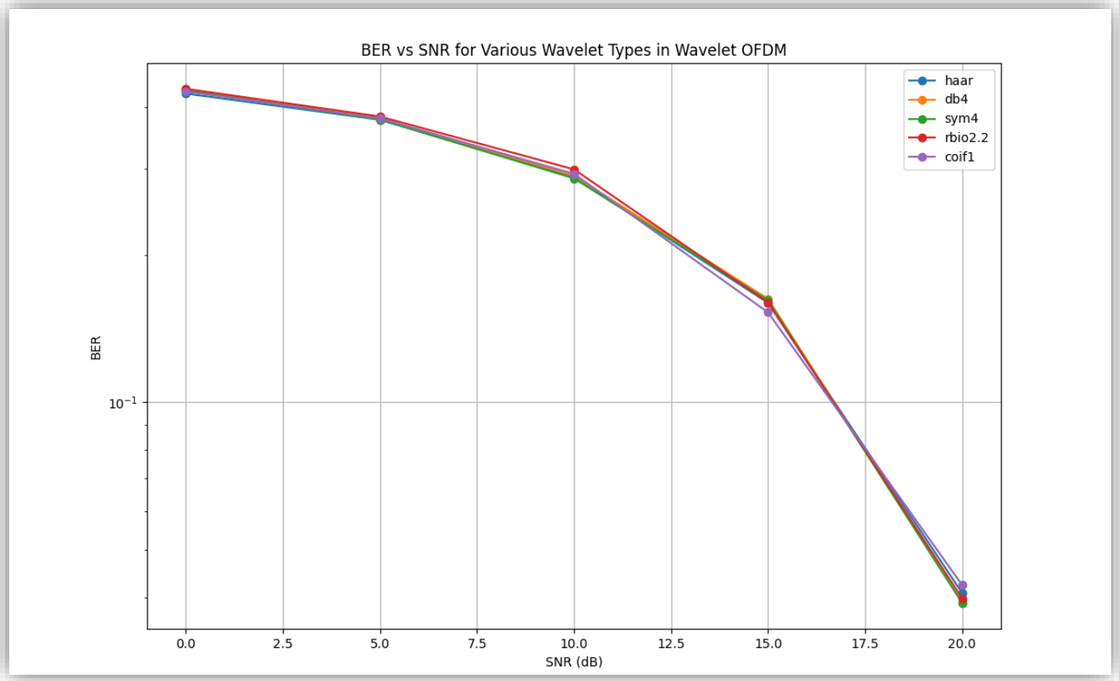
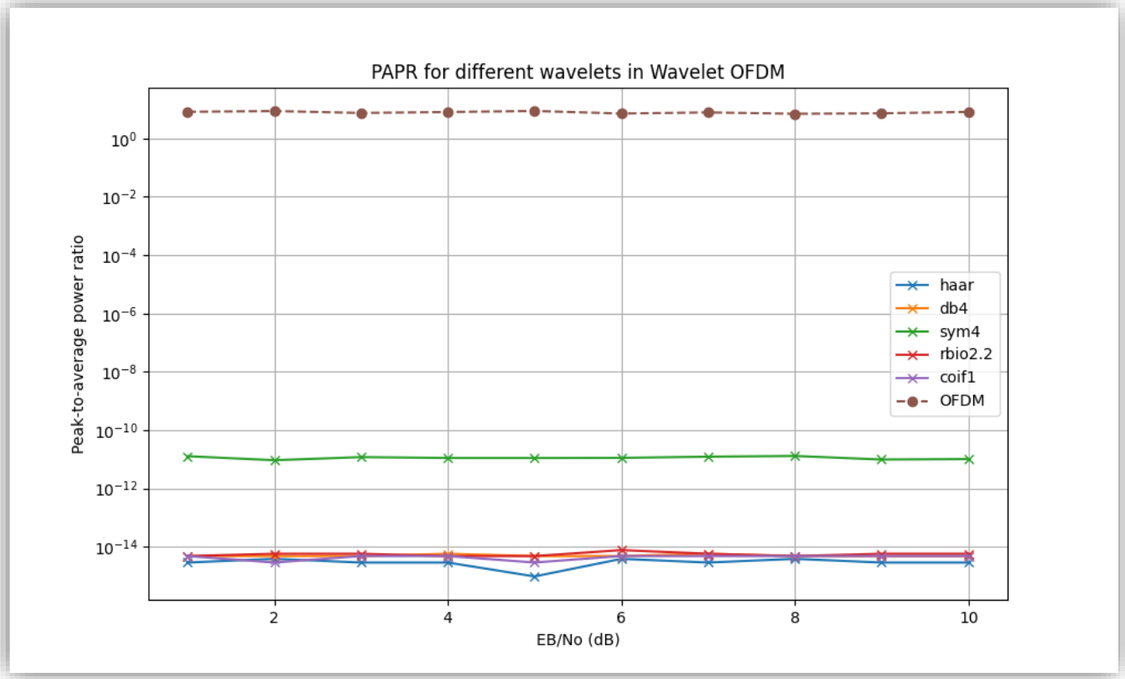
Performance Comparison





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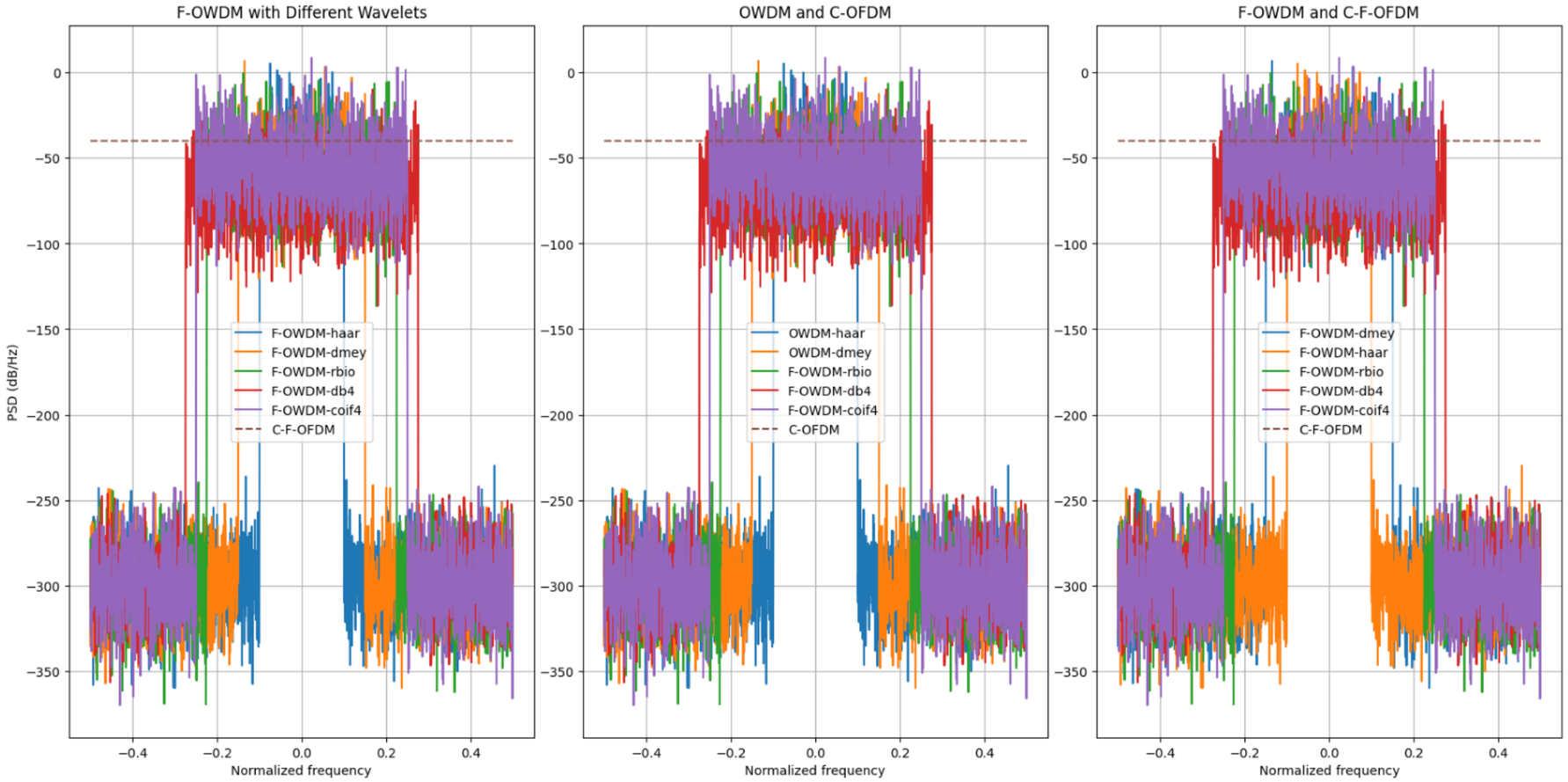
Performance Comparison



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Lessons learnt

Wavelet Transform:

- Wavelet transform decomposes signals into different frequency components with varying resolutions.
- It captures both time and frequency information simultaneously, allowing analysis of transient and non-stationary signals.
- Difference between the transforms we have used in this scenario.
- {Haar, sym4, db4, rbio, coif4}

Implementation:

- The use case of IDWT and the wavelet transforms.

Analysis:

- **Bior** and **haar** based F-OWDM shows better PAPR performance and BER characteristics.
- All the wavelets have better **PSD** characteristics.

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Conclusion

- The Filtered Orthogonal Wavelet Division Multiplexing (F-OWDM) system, analyzed against C-F-OFDM, employs wavelet techniques without cyclic prefix (CP) to conserve bandwidth.
- Peak-to-Average Power Ratio (PAPR) and Bit Error Rate (BER) characteristics under multipath and Additive White Gaussian Noise (AWGN) channels, F-OWDM surpasses C-F-OFDM.
- Notably, the bior2.2 wavelet exhibits superior PAPR and similar spectrum characteristics to C-F-OFDM, indicating F-OWDM as a compelling choice for 5G and beyond applications.

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4. Basic OFDM Example in Python: https://dspillustrations.com/pages/posts/misc/python-ofdm-example.html

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Thank You