Coded
Orthogonal Frequency Division Multiplexing (COFDM)

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OFDM Overview

- Spectrum of normal time domain sequence

- Spectrum of classical frequency division multiplexing (FDM)

- Spectrum of Orthogonal Frequency Division Multiplexing
OFDM Overview

Each of the series of carriers is multiplied by a (complex) scalar from the input data.
SYSTEM REQUIREMENTS

- Orthogonal carriers
- Guard band
- Error Control Coding

BENEFITS

- Performs well in the presence of frequency selective fading
- No ISI, ICI
Carrier Orthogonality

• Whole number of cycles in a symbol period ($\tau$)

• Example: basis functions of the Fourier transform

$\Psi_k(t) = e^{j\omega t}$
Guard band

![Diagram showing channel impulse response and time for 1, 2, and 8 carriers with guard bands between them.](diagram.png)
Guard band

- Guard band is the last $T_g$ seconds of the active symbol period prefixed to the waveform, making it a cyclic prefix.
- Must be kept short, a fraction of $T$, yet longer than the channel impulse response:
  - Completely eliminates ISI, ICI
  - Maintains subcarrier orthogonality
  - Time waveform appears periodic to the receiver.
Multipath Fading

- Two-ray model allows for a main component and a single reflection with magnitude and phase

\[ h(t) = \delta(t) + \Gamma \delta(t-\tau) \]

\[ H(f) = 1 + \Gamma e^{j2\pi f \tau} \]
Multipath Fading

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Multipath Fading

- Spectrum is multiplied by the frequency response of the channel
- Some frequency bins are attenuated, others are amplified
Multipath Fading

Resolved through:

- Interleaving in frequency
- Convolutional coding
- Equalization
The IFFT creates a time domain waveform with the exact frequency content specified by the basis functions of the DFT and the complex constellation points $x_{n,m}$. 

**OFDM System using DFT/FFT**

- Transmitter
  - Input data
  - QPSK map
  - Conv
  - Frequency Interleaver
  - Serial to Parallel
  - IDFT (IFFT)
  - cyclic prefix
  - $s(k)$
  - $h(t)$
  - Channel
  - $n(k)$

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• In the Receiver, the FFT acts as a bank of filters, where the values of the resulting frequency bins become the signal constellation points.
Simulations Results

QPSK mapped OFDM, N=256 carriers

QPSK with 50 ns delay ($G=0.7e^{j0.5\pi}$)

Actual (with null)

Theoretic (no null)

Uncoded $E_b/N_0$ (dB)

Probability of Bit Error

256 carriers, $K=3$

1024 carriers, $K=3$

Theoretical, $K=3$

256 carriers, $K=4$

1024 carriers, $K=4$

Theoretical, $K=4$
Simulation Results

QPSK mapped OFDM, N=256 carriers

QPSK with 50 ns delay ($G = 0.7e^{i0.75\pi}$)

- Actual (with null)
- Theoretic (no null)

Uncoded $E_b/N_0$ vs. Probability of Bit Error

- 256 carriers, $K=3$
- 1024 carriers, $K=3$
- Theoretical, $K=3$
- 256 carriers, $K=4$
- 1024 carriers, $K=4$
- Theoretical, $K=4$
Simulation Results

QP SK mapped OFDM, N=256 carriers

Probability of Bit Error

Phase of Null (radians/p)

Actual (with null)
Theoretic (no null)

QPSK with 50 ns delay \((G=0.7e^{j1p})\)

Uncoded Eb/N0 (dB)
Probability of Bit Error

-5 0 5 10 15

256 carriers, K=3
1024 carriers, K=3
Theoretical, K=3

256 carriers, K=4
1024 carriers, K=4
Theoretical, K=4
Conclusion

• Performs better than a single modulated carrier in multipath fading

• With a properly implemented guard interval:
  – Time waveform appears periodic
  – orthogonality of subcarriers is ensured
  – ISI and ICI are eliminated