IMAGE TRANSMISSION OVER AWGN/ FADING CHANNELS USING OFDM & Performance Analysis

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Outline

- What is OFDM and Application
- OFDM System Model
- Why OFDM
- Multipath channels (Parameters & Types)
- Why OFDM in Multipath Channels
- Simulation Results
- Table of PSNR Comparison
- Future Work
Instead of transmitting the data stream in a serial way, we partition our data to \textit{N blocks of data} and transmit them in \textit{PARRALEL} with lower data rate.

Each sub-stream is modulated separately and transmitted on a different carrier. The frequency spacing between these carriers is kept equal. As a result, these carriers become orthogonal to each other.

& the Key is: Orthogonality allows simultaneous transmission on a lot of sub-carriers in a tight frequency space without interference from each other.
Orthogonal Frequency Division Multiplexing (Cont.)

**EXAMPLE:**
1, 1, -1, -1, 1, 1, -1, -1, 1, -1, -1, 1, -1, -1, 1, ...

<table>
<thead>
<tr>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
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</thead>
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<td>-1</td>
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<tr>
<td>1</td>
<td>....</td>
<td></td>
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</tbody>
</table>

**BPSK**

Symbol Rate (Data Rate), 1
for Subcarriers, Bit rate is 1/4
Nyquist Frequency is 1/2
Subcarriers Freq.
1/2 Hz, 1 Hz, 3/2 Hz, 2 Hz
Application of OFDM

- HDTV-High bit rate Digital(European & Australian Standard)
- ADSL (Asymmetric Digital Subscriber Loop)
  - High Speed data transmitted along existing telephone lines
- IEEE 802.11 (a, g) Wireless-LAN Standard
Basic OFDM SYSTEM Model

Data in

S/P → Modulation (BPSK, QPSK, QAM, etc) → IDFT (IFFT) → P/S → Baseband OFDM signal

Data out

P/S → Demodulation (BPSK, QPSK, QAM, etc) → DFT (FFT) → S/P → Baseband OFDM signal

Channel

AWGN/Fading
inverse Fourier transform is used to find the corresponding time waveform. (Orthogonal Carriers)

\[
s_m(n) = \begin{cases} 
\frac{1}{N_c} \sum_{k=0}^{N_c-1} x_{k,m} e^{j2\pi k(n-N_{cp})/N_c}, & \text{if } n \in [0, N_c + N_{cp} - 1] \\
0, & \text{otherwise}
\end{cases}
\]

\[
y_{k,m} = \sum_{n=0}^{N_c-1} \left( \frac{1}{N_c} \sum_{k=0}^{N_c-1} \left( \sum_{\eta=0}^{N_c-1} h(\eta) e^{-j2\pi k\eta} \right) x_{k,m} e^{j2\pi kn/N_c} \right) e^{-j2\pi kn/N_c} + n_{k,m}
\]

\[
\underbrace{\text{IDFT}}_{\text{DFT}}
\]
Advantages & Drawback

- Multi-path Delay Spread Tolerance
- Tolerance to ISI
- Spectral Utilization Efficiency (overlapping transmit spectra)

Drawbacks
- Peak-to-Average power ratio (PAPR) or the large dynamic range of the signal. Clipping is used to overcome the problem.
- Sensitivity to frequency errors.
Why OFDM is Popular?

- Most Wireless Communication Systems are subject to Multipath
- The main solution is complicated equalizers
- Dealing with Multipath is Simpler using OFDM
Multipath Environment

Diagram showing various paths and components in a multipath environment, including a transmitter, receiver, buildings, moving scatterers, and an airplane.
Small-Scale Fading: Parameters & Types

- Multipath waves can cause rapidly changing channel conditions over distances on the order of meters.

- The short term variation in signal strength and parameters, by the local multipath is *small-scale fading*, & is observed over distances of about half a wavelength.

  - Long-term variation in the mean signal is *Large-scale fading*.
Rayleigh Distribution

- Rayleigh Distribution is used to model the statistical characteristic of the multipath channels. (NLOS)

  & most common for statistically describing envelope of a flat fading signal

\[
p(r) = \begin{cases} 
  \frac{r}{\sigma^2} \exp \left( -\frac{r^2}{2\sigma^2} \right) & 0 \leq r < \infty \\
  0 & r < 0 
\end{cases}
\]
Parameters: Delay Spread
(Exponential Power Delay Profile)

\[
P_g(\tau) = \begin{cases} 
\frac{1}{\sqrt{2\pi}S} \exp \left( -\frac{(\tau - \bar{\tau})^2}{2S^2} \right), & \tau \geq 0, \\
0, & \text{Otherwise}
\end{cases}
\]
$S$: is rms delay spread

$$P_e = \begin{cases} \frac{1}{S} \exp\left(-\frac{\tau}{S}\right), & \tau \geq 0, \\ 0, & Otherwise \end{cases}$$

$$\tau = 4S$$
Parameters: Doppler Spread

\[ f_d = \frac{1}{2\pi} \cdot \frac{\Delta \varphi}{\Delta t} = \frac{v}{\lambda} \cdot \cos \theta \]
Doppler Spectrum

Conditions:

- Mobile receiver moves with a constant velocity
- Signal power received by antenna uniformly from all incident angles in $[0, 2\pi]$

If receiver is static; Doppler Spectrum is an Impulse located at Carrier Frequency.

$$S(f) = \frac{K}{\sqrt{1 - \left(\frac{f - f_c}{f_{\text{max}}}\right)^2}}$$
Types of Small Scale-Fading (1)

Based on Delay Spread

Flat Fading
- BW of Signal < BW of channel
- Delay Spread < Symbol period

Frequency Selective Fading
- BW of Signal > BW of channel
- Delay Spread > Symbol period

Flat Fading Channel: the one which passes all spectral components with equal gain and linear phase.

Frequency-Selective Fading: Fading does not occur uniformly. Some frequencies will be cut. (some information vanishes)

Environment chooses these frequencies.
Types of Small Scale Fading (2)

Based on Doppler Spread

- Fast Fading
  - High Doppler Spread
  - Coherence Time < Symbol Period
    - Channel Variations faster than baseband signal variations

- Slow Fading
  - Low Doppler Spread
  - Coherence Time > Symbol Period
    - Channel Variations slower than baseband signal variations
Clarke’s Model for Flat Fading
(Rayleigh Fading Simulator)
Clarke’s Model for Flat Fading (Cont.)

- This Model uses the concept of In-Phase & Quadrature fading branches.
- The filter below is used to shape the signals in frequency domain. (U shape)

\[
S_{Ez}(f) = \frac{1.5}{\pi f_m \sqrt{1 - \left( \frac{f - f_c}{f_m} \right)^2}}
\]

- IFFT: to accurate Time-domain waveform of Doppler fading. &
- \( f_m \) is Maximum frequency component of Line Spectrum.
Clarke’s Model (Frequency Selective Fading)
How OFDM Solves Multipath Problem?

- Data is transmitted in Parallel
  - Longer Symbol Period
  - For Example: for N parallel Streams, Symbol Period is N times as Long

- It avoids ISI (Cyclic Prefix)
Simulation Results

Tested Pictures
OFDM over AWGN Channel
Comparison Results of Theoretical and Simulation of OFDM performance over AWGN channel

$$P_{e,BPSK} = \frac{1}{2} \text{erfc}(\sqrt{\gamma}) \quad \gamma = \frac{E_b}{N_0} \triangleq \text{SNR}$$
OFDM over Flat Slow Fading
OFDM over Flat Fast Fading
OFDM over Frequency-Selective Slow Fading
OFDM over Frequency-Selective Fast Fading
OFDM over Frequency-Selective Fast Fading (Cont.)
<table>
<thead>
<tr>
<th>Channel/ SNR</th>
<th>AWGN</th>
<th>Flat Slow Fading</th>
<th>Flat Fast Fading</th>
<th>Frequency Selective Slow Fading</th>
<th>Frequency Selective Fast Fading</th>
</tr>
</thead>
<tbody>
<tr>
<td>3dB</td>
<td>21.2433 dB</td>
<td>17.2312 dB</td>
<td>16.3040 dB</td>
<td>15.1126 dB</td>
<td>11.5842 dB</td>
</tr>
</tbody>
</table>
Future Work

- Different modulation (QAM)
- Cyclic Prefix
- Error-Coding
- Equalizers
- Ricean Distribution (LOS)
- MIMO OFDM
THANK you all for Listening

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