University of Moratuwa
Department of Electronic and Telecommunication Engineering

EN4384 - Wireless and Mobile Communications
Workshop 2

Welcome to Workshop 2 of EN4384. This workshop focuses on OFDM.

There are 20 marks available for the successful completion of all tasks in this workshop. This workshop is worth 5% of your overall mark for the module.

You need to prepare a report with your responses to all the tasks and submit it by the deadline indicated on the Moodle page. You may hand-write or use MS Word or LaTeX, as per your convenience. To perform the simulation tasks, you need to use MATLAB.

Abstract: This workshop provides a hands-on simulation study of **Orthogonal Frequency Division Multiplexing (OFDM)**, a core modulation technique in 4G/5G broadband systems. Using MATLAB, students will implement a baseband OFDM system with modulation, IFFT-based multicarrier generation, cyclic prefix insertion, and AWGN channel transmission. The goal is to visualize subcarrier orthogonality, evaluate BER performance, and understand the role of cyclic prefix (CP) in mitigating inter-symbol interference (ISI).

Background Theory

Concept of OFDM

Orthogonal Frequency Division Multiplexing divides the available channel bandwidth into many orthogonal narrowband subcarriers. Each subcarrier transmits data symbols (e.g., QPSK, 16-QAM) simultaneously, improving spectral efficiency and robustness to frequency-selective fading. Mathematically, an OFDM symbol with N subcarriers is generated as:

$$s[n] = \frac{1}{N} \sum_{k=0}^{N-1} X_k e^{j2\pi kn/N}, \quad n = 0, 1, \ldots, N-1$$

where X_k are the modulated data symbols. This is efficiently computed using the IFFT.

Cyclic Prefix (CP)

A cyclic prefix is a copy of the last N_{CP} samples of the OFDM symbol appended in front. It absorbs ISI caused by multipath delay spread and converts the channel convolution into a circular one, simplifying equalization in the frequency domain.

System Model

Bitstream → Mapper → IFFT → Add CP → Channel → Remove CP → FFT → Demapper

Task 1: Baseband OFDM Implementation (AWGN Channel)

Description

Implement a basic OFDM system (no channel distortion). Transmit random bits using QPSK over multiple subcarriers. Observe how increasing SNR reduces BER.

MATLAB Implementation

```
% Parameters
N = 64;                 % Subcarriers
Ncp = 16;               % Cyclic prefix length
Nsym = 1000;            % OFDM symbols
M = 4;                  % QPSK modulation
SNRdB = 0:2:20;

% Transmitter
bits = randi([0 M-1], N*Nsym, 1);
symbols = pskmod(bits, M, pi/M);      % QPSK symbols
tx_matrix = reshape(symbols, N, Nsym);
ifft_out = ifft(tx_matrix, N);        % OFDM modulation
cp = ifft_out((N-Ncp+1):N, :);        % Cyclic prefix
tx_sig = [cp; ifft_out];              % Append CP
tx_sig = tx_sig(:);

% Channel and Receiver
for snr_i = 1:length(SNRdB)
    rx = awgn(tx_sig, SNRdB(snr_i), 'measured');
    rx_matrix = reshape(rx, N+Ncp, Nsym);
    rx_noCP = rx_matrix(Ncp+1:end, :);
    fft_out = fft(rx_noCP, N);
    rx_bits = pskdemod(fft_out(:), M, pi/M);
    [numErr, ber(snr_i)] = biterr(bits, rx_bits);
end

% Plot BER
figure; semilogy(SNRdB, ber, '-o');
xlabel('SNR (dB)'); ylabel('BER');
title('OFDM over AWGN channel');
grid on;
```

Expected Output

- BER curve decreases exponentially with increasing SNR.
- For $M = 4$ (QPSK), BER $\approx 10^{-3}$ at SNR ≈ 12 dB.
- The signal in the time domain appears noise-like; spectrum shows distinct subcarriers.

Task 2: Effect of Cyclic Prefix Length

Description

Now introduce a simple multipath channel and observe the effect of CP length. Channel model:

$$h = [0.9, 0.5, 0.3];$$

Simulate with and without sufficient CP.

MATLAB Simulation

```
h = [0.9 0.5 0.3];      % Simple multipath channel
Ncp_vec = [4 8 16 32];
snr = 15;                % fixed SNR
ber_cp = zeros(size(Ncp_vec));

for c = 1:length(Ncp_vec)
    Ncp = Ncp_vec(c);
    cp = ifft_out((N-Ncp+1):N,:);
    tx = [cp; ifft_out];
    tx_chan = conv(tx(:), h, 'same');
    rx = awgn(tx_chan, snr, 'measured');
    rx_matrix = reshape(rx, N+Ncp, Nsym);
    rx_noCP = rx_matrix(Ncp+1:end, :);
    fft_out = fft(rx_noCP, N);
    rx_bits = pskdemod(fft_out(:), M, pi/M);
    [~, ber_cp(c)] = biterr(bits, rx_bits);
end

figure; plot(Ncp_vec, ber_cp, '-s');
xlabel('Cyclic Prefix Length'); ylabel('BER');
title('Impact of CP length on BER (Multipath Channel)');
grid on;
```

Expected Observations

- When CP length $\geq$ channel length, BER matches AWGN-only case.
- Insufficient CP causes inter-symbol interference, increasing BER.
- CP trades bandwidth efficiency for robustness.

Task 3: Frequency-Selective Channel Equalization

Description

Introduce a channel frequency response and apply per-subcarrier equalization using one-tap complex division in the frequency domain.

```
H = fft(h, N).';        % Channel frequency response
fft_eq = fft_out ./ repmat(H,1,Nsym);
rx_bits_eq = pskdemod(fft_eq(:), M, pi/M);
[~, ber_eq] = biterr(bits, rx_bits_eq);
```

Expected Result

- Equalization significantly restores performance even for long multipath channels.
- Flat subcarriers show uniform SNR; frequency nulls may still degrade few tones.

Task 4: Advanced Experiments (Optional)

- Implement 16-QAM mapping and observe BER–SNR tradeoff.
- Plot constellation before and after channel equalization.

- Add Doppler effect (time-varying fading) using `rayleighchan`.
- Explore pilot-based channel estimation.

Deliverables

- BER vs. SNR and BER vs. CP-length plots. (10 marks)
- Short report (2–3 pages) analyzing performance trends and practical implications.
  1. Why does OFDM maintain orthogonality despite overlapping subcarriers?
  2. What is the effect of increasing the number of subcarriers N?
  3. How does cyclic prefix length influence system bandwidth efficiency?
  4. Compare OFDM to single-carrier systems under multipath fading.

(10 marks)