Mini Project - Application Example of OFDM: The IEEE 802.11a Wireless LAN Standard

Digital Communications, EEEN3009J, Autumn 2020/21

The IEEE 802.11a Wireless LAN standard, which occupies 20 MHz of bandwidth in the 5 GHz unlicensed band, is the first version of 802.11 family that is based on OFDM. The 802.11g standard is virtually identical, but operates in the smaller and more crowded 2.4 GHz unlicensed ISM band. IEEE 802.11ac, released in December 2012, also operates in the 5 GHz band. It uses a wider RF bandwidth (80 or 160 MHz), multiple-input multiple-output (MIMO) technology (up to 8 MIMO streams), high-density modulation (up to 256 QAM) and could deliver a maximum data rate close to 7Gbps (on eight 256-QAM channels each delivering 866.7 Mbps). The properties of OFDM design used in 802.11a standard and some of the design choices are discussed below.

48*6 data bits+16*6 zeros=64*6

In 802.11a standard, $N = 64$ subcarriers are generated. However, only 48 carriers are actually used for data transmission, the outer 12 carriers are zeroed in order to reduce adjacent channel interference, and 4 carriers used as pilot symbols for channel estimation and synchronization. The cyclic prefix consists of $\mu = 16$ samples, so the total number of samples associated with each OFDM symbol, including both data samples and the cyclic prefix, is 80. The transmitter gets periodic feedback from the receiver about the packet error rate, and uses this information to pick an appropriate error correction code and modulation scheme. The same code and modulation must be used for all the subcarriers at any given time. The error correction code is a convolutional code with one of three possible code rates: $r_c = 1/2, 2/3,$ or $3/4$. The modulation types that can be used on the subchannels are BPSK, QPSK, 16-QAM, or 64-QAM.

16+64=80

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The bandwidth B (and sampling rate $1/T_s$) is 20 MHz, and there are 64 subcarriers evenly spaced over that bandwidth. Therefore the subcarrier bandwidth is:

$$B_N = \frac{20}{64}\ \text{MHz} = 312.5\ \text{KHz} \tag{1}$$

Since $\mu = 16$ and $1/T_s = 20$ MHz, the maximum delay spread for which ISI is removed is

$$T_m = \mu T_s = \frac{16}{20\ \text{MHz}} = 0.8 \times 10^{-6}\text{sec} \tag{2}$$

which corresponds to delay spread in an indoor environment. Including both the data and cyclic prefix, there are 80=64+16 samples per OFDM symbol. Thus the symbol time per subchannel is

$$T_N^{(+CP)} = T_N + \mu T_s = (N+\mu)T_s = 80T_s = \frac{80}{20\times 10^6} = 4\times 10^{-6}\text{sec} \tag{3}$$

The data rate per subchannel is $\log_2 M/T_N^{(+CP)}$. Thus, the minimum data rate for this system, corresponding to BPSK (1 bit/symbol), an $r = 1/2$ code, and taking into account that only 48 subcarriers actually carry information data, is given by

$$(r_b)_{min} = 48 \text{ sub.} \times \frac{1/2 \text{ bit}}{\text{coded bit}} \times \frac{1 \text{ code bit}}{\text{sub. symbol}} \times \frac{1 \text{ sub. symbol}}{4\times 10^{-6}} = 6 \text{ Mbps} \tag{4}$$

The maximum data rate corresponds to 64-QAM and $r = 3/4$ code. It is given by,

$$(r_b)_{min} = 48 \text{ sub.} \times \frac{3/4 \text{ bit}}{\text{coded bit}} \times \frac{6 \text{ code bit}}{\text{sub. symbol}} \times \frac{1 \text{ sub. symbol}}{4\times 10^{-6}} = 54 \text{ Mbps} \tag{5}$$

Naturally, a wide range of data rates between these two extremes is possible. Write a MATLAB program to simulate the time-domain OFDM design of IEEE 802.11a.

The following are the requirements:

- The program should include the OFDM transmitter, equivalent discrete-time channel, AWGN and OFDM demodulator.
- For the equivalent discrete-time channel, generate the channel filter coefficients $h[n]_{n=0}^{\mu}$ as i.i.d. zero-mean complex Gaussian random variables, with variance 1/2 for real and imaginary parts.
- For the OFDM demodulator you can assume that the channel coefficients $h[n]_{n=0}^{\mu}$ are perfectly known.
- Test your MATLAB program with 64-QAM modulation on all data subcarriers and 卷积码参数 $r_c = 1/2, 2/3, 3/4$ and obtain a plot of the bit error rate versus received E_b/N_0. In the same set of axes there should be three separate plots for $r_c = 1/2, 2/3, 3/4$ with proper labelings.
- Your program should consist of a single m-file script, and should be appropriately annotated with comments. You should not use any procedures from the MATLAB communications toolbox.
- Your assignment should be submitted via Brightspace, and should contain two files:

(a) Your MATLAB simulation m-file, and

(b) A short report (**in PDF format**) containing the system performance graph(s) and other important outputs of your codes. A brief commentary about the methods you used and the results you obtained should also be included in this report. The answers to the specific questions asked above should also be stated clearly in your report.

- The deadline is **11:30 pm (Dublin time) on Friday 18 December 2020**.
- **And most importantly:** The program you submit should be **your own work**. Programs will be scrutinized for evidence of copying. Programs in which copying is found will NOT be awarded a pass grade.