Design of OFDM model and performance analysis

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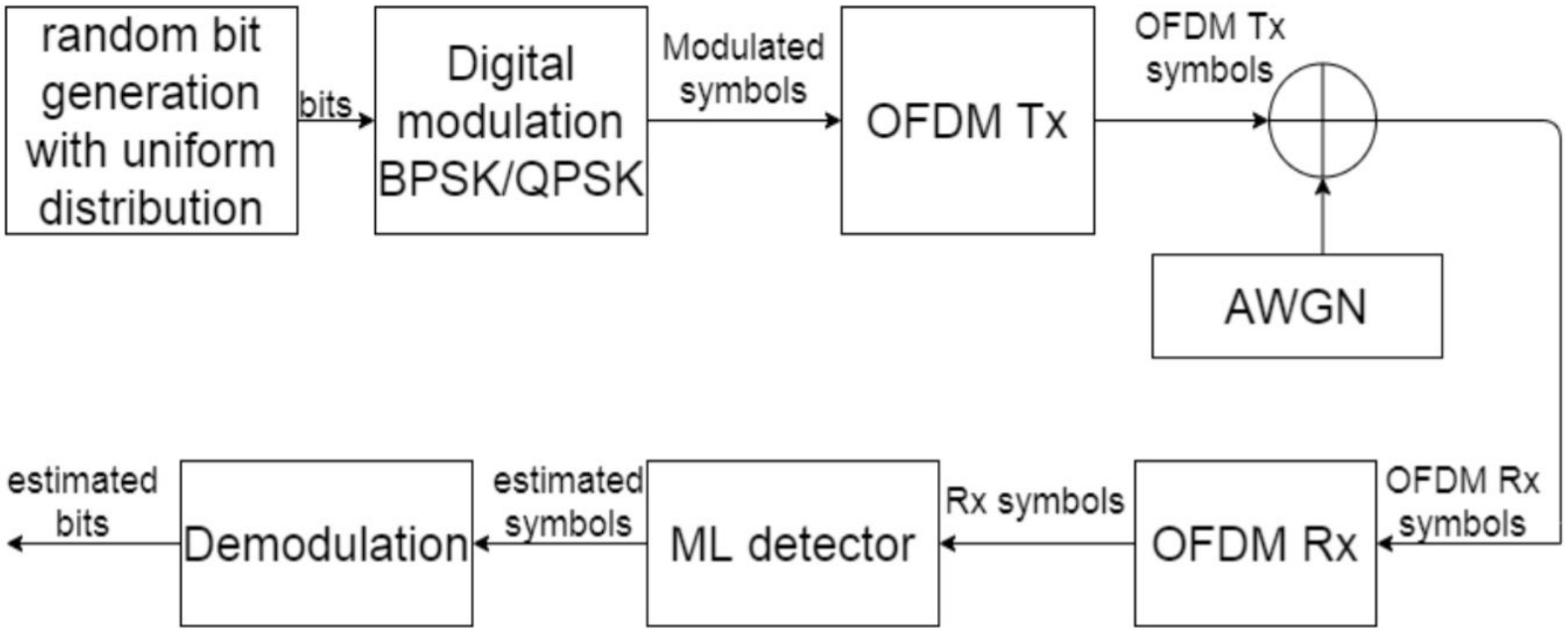
Project Objective

- To demonstrate functionality of OFDM using SDSoC and Zedboard
  - Understand algorithm used in OFDM design
  - Implement using C/C++ in SDSoC
  - Hardware Software co-design
  - In-Depth performance analysis
  - In-Depth complexity analysis

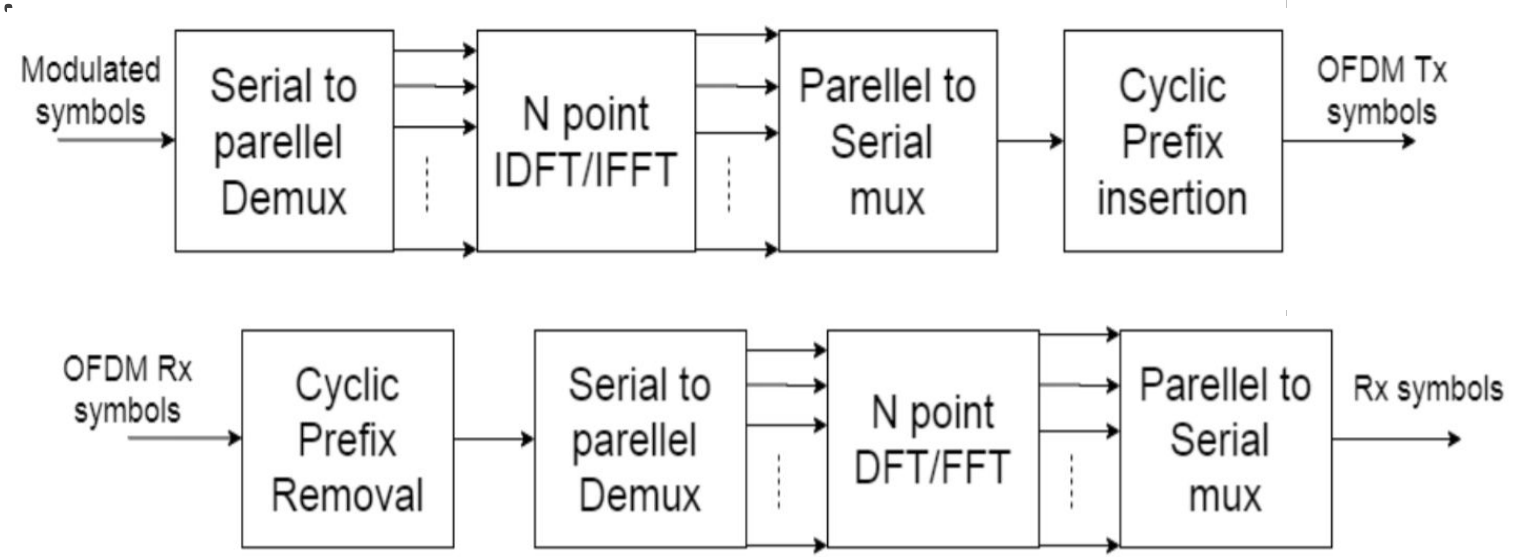
Why OFDM ?

- Form of multicarrier modulation
- Subcarriers are orthogonal to each other
- Less Intersymbol interference
- No Guard-bands
- Bandwidth efficient
- High speed data transmission, Used in 4G LTE.

Block Diagram of OFDM Tx and Rx with AWGN



OFDM Tx and Rx



Modulation/Demodulation of Digital symbols

- BPSK symbol set= {1,-1}

  Average energy $E_s = 1$
- QPSK symbol set ={1+1i, 1-1i, -1+1i, -1-1i}

  Average energy $E_s = 2$

To make total energy of symbol set=1, we need to multiply the set with a factor of **1/sqrt(2)**

```
24 //BPSK modulation
25 void bpskNumberGenerator(float *data,float *x_k_bpsk){
26
27     for(int i = 0;i<FFTSize;i++)
28 {
29         x_k_bpsk[i]=(1/sqrt(2))*(2*data[i]-1);
30         printf("BPSKInput:%f ",x_k_bpsk[i]);
31 }
32
33 }
```

```
//BPSK demodulation
void bpskNumberGeneratorRX(float *x_k_fft,float *dataout){

    for(int i = 0;i<FFTSize;i++)
{
        dataout[i]=(x_k_fft[i]+1)/2;
        printf("dataOut:%f ",dataout[i]);
}

}
```

IDFT/IFFT

- IDFT: $x[N]= \frac{1}{N}\sum_{k=0}^{N-1} X[k]e^{j2\pi nk/N} \quad , \quad n = 0,1, \dots \dots, N-1$

- Matrix form:

$$\begin{bmatrix} x[0] \\ \vdots \\ x[N-1] \end{bmatrix} = \frac{1}{\mathrm{N}} \begin{bmatrix} 1 & \cdots & 1 \\ \vdots & \ddots & \vdots \\ 1 & \cdots & W_N^{(N-1)(N-1)} \end{bmatrix} \begin{bmatrix} X[0] \\ \vdots \\ X[N-1] \end{bmatrix}$$

Cyclic prefix Insertion/Removal :

- After IFFT : $[x_1\ x_2 \cdots x_{N-L+1} \cdots x_N]$
- After CP insertion :

$$[x_{N-L+1} \cdots x_N\ x_1\ x_2 \cdots x_{N-L+1} \cdots x_N]$$

- Ex: In 4G, IFFT/FFT size is N = 2048 and length of CP is L = 144

ML Detector algorithm

ML detector(minimum distance decoder)

$estimated\ symbol\ x' = \min_{x \in C} |y - x_2|^2$

- Ex: For BPSK, $C = 1, -1 = \{x_1, x_2\}$

1. find $d_1 = y - x_1$ and $d_2 = y - x_2$
2. if $d_1 > d_2$, then $x' = x_2$

else if $d_1 < d_2$, then $x' = x_1$

- In demodulation estimate the bits from symbol

Pseudo code for OFDM Model

- for iter = 1:N
  - Bit generation
  - Mapping to symbol(BPSK/QPSK)
  - IFFT/IDFT
  - Cyclic Prefix Insertion
  - AWGN
  - Cyclic Prefix Removal
  - FFT/DFT
  - ML detector
  - Estimate bit error

end

Results / Demo

Matlab result

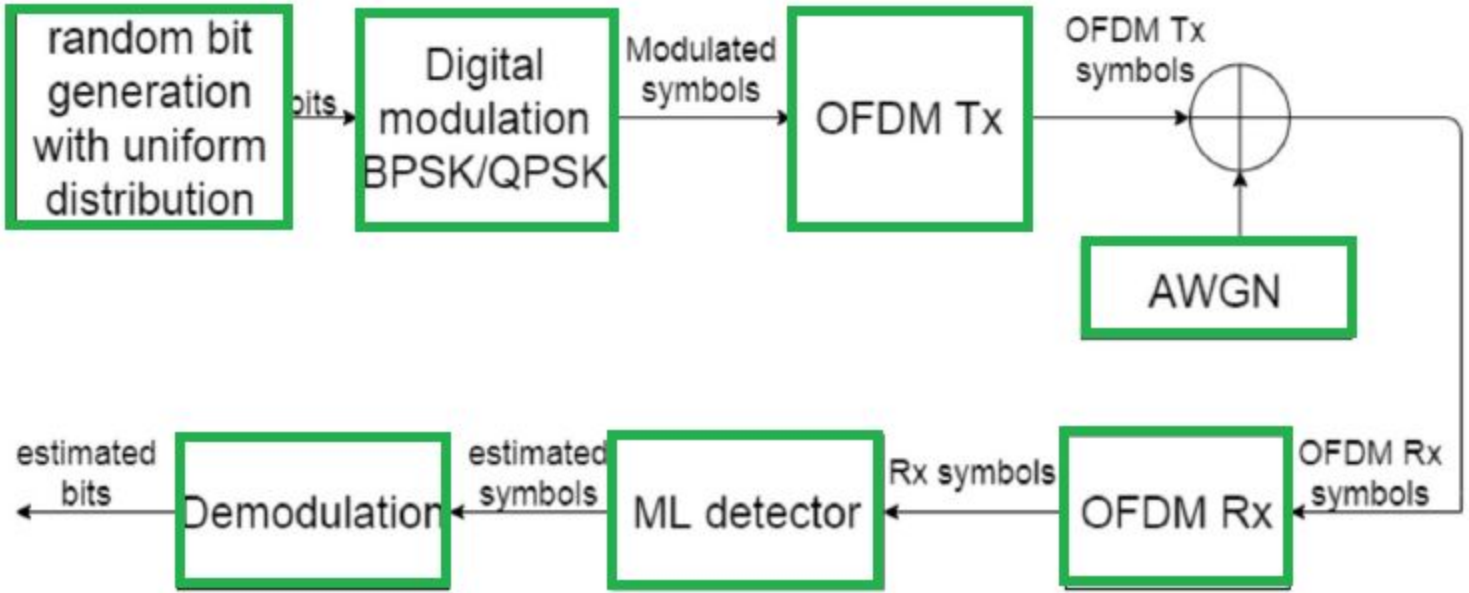
```
a =

    0.7070    0.7070   -0.7070    0.7070   -0.7070   -0.7070   -0.7070   -0.7070

>> dft=ifft(a)

dft =

  -0.1767 + 0.0000i   0.1767 + 0.2500i   0.1767 + 0.0000i   0.1767 + 0.2500i  -0.1767 + 0.0000i   0.1767 - 0.2500i   0.1767 + 0.0000i   0.1767 +
0.2500i

>> fft=fft(dft)

fft =

    0.7070    0.7070   -0.7070    0.7070   -0.7070   -0.7070   -0.7070   -0.7070
```

```
Starting PL simulation

################################ Start of 1 iteration ###################################################

--------- Tx side Generation of random data in binary form------------------
DataInput:1.000000 DataInput:1.000000 DataInput:0.000000 DataInput:1.000000 DataInput:0.000000 DataInput:0.000000 DataInput:0.000000 DataInput:0.000000

--------- Tx side Generation of BPSK signal with normalization factor-------------------
BPSKInput:0.707107 BPSKInput:0.707107 BPSKInput:-0.707107 BPSKInput:0.707107 BPSKInput:-0.707107 BPSKInput:-0.707107 BPSKInput:-0.707107 BPSKInput:-0.707107


--------- Tx side Performing IDFT on BPSK signal -------------------
IFFTInput:-0.176777 j* 0.000000
IFFTInput:0.176777 j* 0.250000
IFFTInput:0.176777 j* -0.000000
IFFTInput:0.176777 j* 0.250000
IFFTInput:-0.176777 j* 0.000000
IFFTInput:0.176777 j* -0.250000
IFFTInput:0.176777 j* 0.000000
IFFTInput:0.176777 j* -0.250000


--------- Tx side Adding cyclic prefix to IDFT signal -------------------
cyclicTx:0.176777 j* -0.250000
cyclicTx:0.176777 j* 0.000000
cyclicTx:0.176777 j* -0.250000
cyclicTx:-0.176777 j* 0.000000
cyclicTx:0.176777 j* 0.250000
cyclicTx:0.176777 j* -0.000000
cyclicTx:0.176777 j* 0.250000
cyclicTx:-0.176777 j* 0.000000
cyclicTx:0.176777 j* 0.000000
```

```
---------- Rx side Removing cyclic prefix from Tx signal --------------------
cyclicRx:-0.176777 j* 0.000000
cyclicRx:0.176777 j* 0.250000
cyclicRx:0.176777 j* -0.000000
cyclicRx:0.176777 j* 0.250000
cyclicRx:-0.176777 j* 0.000000
cyclicRx:0.176777 j* -0.250000
cyclicRx:0.176777 j* 0.000000
cyclicRx:0.176777 j* -0.250000


--------- Rx side Performing DFT on Rx_side_Cyclic_data ------------------
FFTOutput:0.707107 +j*-0.000000
FFTOutput:0.707107 +j*0.000000
FFTOutput:-0.707107 +j*0.000000
FFTOutput:0.707107 +j*-0.000000
FFTOutput:-0.707107 +j*0.000000
FFTOutput:-0.707107 +j*-0.000000
FFTOutput:-0.707107 +j*0.000000
FFTOutput:-0.707107 +j*-0.000000


--------- Rx side ML decoding of DFT signal -------------------
DicisionOut:1.000000
DicisionOut:1.000000
DicisionOut:-1.000000
DicisionOut:1.000000
DicisionOut:-1.000000
DicisionOut:-1.000000
DicisionOut:-1.000000
DicisionOut:-1.000000

--------- Rx side Demodulation and generation of BPSK signal -------------------

dataOut:1.000000 dataOut:1.000000 dataOut:0.000000 dataOut:1.000000 dataOut:0.000000 dataOut:0.000000 dataOut:0.000000 dataOut:0.000000

--------- Calculation of Bit Error probability-------------------
Error-> 0.000000

--------- Comparison between Input data and Output data-------------------
PASS-GOODWORK
```

SDSoc result

Work done till Now



Future plan

- Implementation of OFDM model using QPSK modulation and demodulation.
- Implementation of Butterfly FFT and IFFT in OFDM model in Hardware.
- LS estimator Design
- Performance and complexity analysis of OM model in HW and SW co-design

Challenges faced

- When we introduce AWGN noise in Tx signal.We are getting high bit error,So either AWGN algorithm having issue or ML decoder.
- Design of MIMO Structure in C code.
- Design of ML decoder for QPSK/BPSK.