Comparing f-OFDM and OFDM Performance for MIMO Systems Considering a 5G Scenario

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Keywords

Out of Band Emission(OOBE)

OOBE is an emission on a frequency or frequencies immediately outside the necessary bandwidth.

Orthogonal Frequency Division Multiplexing(OFDM)

It is a form of signal waveform or modulation that provides some significant advantages.

filtered Orthogonal Frequency Division Multiplexing(f-OFDM)

It is a modification of OFDM by adding a filter.

Introduction

- The expectation for 5G and everything it promises to offer is great.
- The new services are defined by 3rd Generation Partnership project(3GPP)

3GPP

1. Ultra Reliable Low Latency Communications (URLLC): low latency communications and high reliability,
2. Enhanced Mobile Broadband (eMBB): communications with higher data rate and spectral efficiency.
3. massive Machine Type Communications (mMTC):massive communications between machines, with low complexity and power consumption.

Introduction(Contd.)

- Besides these already proposed models and their potentials,there are some important services not being discussed,which serve the needs of low population density areas.
- The 5G RANGE proposes the unlicensed allocation of TVWS(TV-White Spaces) in Very High Frequency and High Frequency, and as a secondary user which significantly reduces network costs.

Secondary User Scenario

Requirement

In this secondary user scenario, it is required to employ a physical layer waveform which reduces OOBE and hence reduces interference with the Primary users.

The requirement justifies the use of f-OFDM, which has its operation based on OFDM signal filtering reducing OOBE.

Benefits of f-OFDM

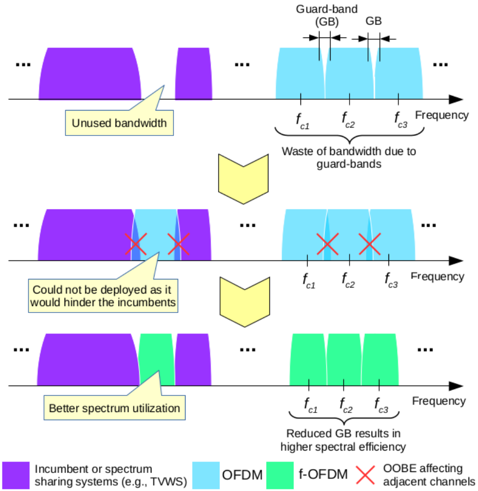


Figure: Signals at adjacent frequencies.

Objective

- The aim of this work is to show the results obtained by simulation comparing OFDM and f-OFDM techniques in Multiple Input Multiple Output systems(MIMO).
- It also evaluates the performance of various MIMO detectors.

Various MIMO detectors

- Maximum Ratio Combining (MRC)
- Zero Forcing (ZF)
- Minimum Mean Squared Error(MMSE)
- Maximum Likelihood (ML)
- Sphere Decoding (SD)

- Particular attention is paid to SD as it's performance is similar to ML with reduced complexity.

System Model

- The employed study model was MIMO for transmission and reception in two scenarios.
  1. Each transmitted signal goes through OFDM modulation.
  2. Each transimtted signal goes through f-OFDM modulation.
- The model is based on transmission sets of four signals at 3 different frequencies(f_{c1}, f_{c2}, f_{c3}) as shown in figure 1, in both scenarios as it is possible to evaluate the effect of filtering on OFDM signals.
- We consider K=4 single antenna devices continuously transmitting signals at each one of the three available frequencies and a Base Station equipped with M antennas receiving and demodulating these signals.

System Model(contd.)

- Here, we create an OFDM symbol by applying a 128 point IFFT to the input signal, however only 72 subcarriers are used for transmission.(remaining is left for guard band).
- The subcarriers are placed at 15KHz apart, that implies 72 x 15 =1.08MHz of useful bandwith.
- This is equivalent to a 1.4 MHz LTE signal where 1.08 MHz is the useful bandwidth and the rest is for guard band.

System Model Equation

The received signals from K antennas at a BS which is equipped with M antennas can be modeled as

$$y = Hs + n \tag{1}$$

where

- s is $K \times 1$ transmitted signal vector
- y is $M \times 1$ received signal vector
- H is $M \times K$ channel matrix
- n is $M \times 1$ Guassian noise vector

Hypothetical System Model

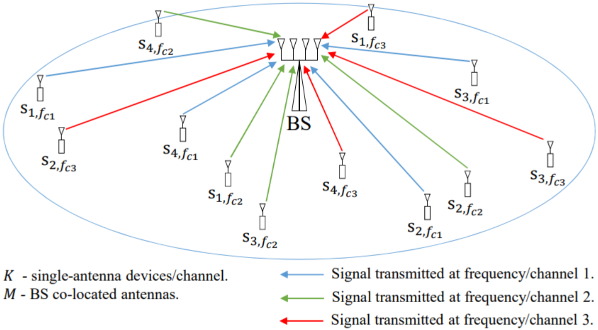


Figure: System model

Results and Discussion

Extent of reduction in OOBE

- We employ the system model depicted in figure 2 and focus on the detection and performance of the signal at central frequency.
- In figure 3 we can see the power spectral density(PSD).
- We can see that the addition of FIR filter drastically reduces the OOBE.
- This reduction ranges from $-40dBW/Hz$ to $-100dBW/Hz$, $-110dBW/Hz$,$-120dBW/Hz$ at a frequency of $0.4 \times fs$ (fs is sampling rate) with FIR filters of order 32,64,128 respectively.

Comparison

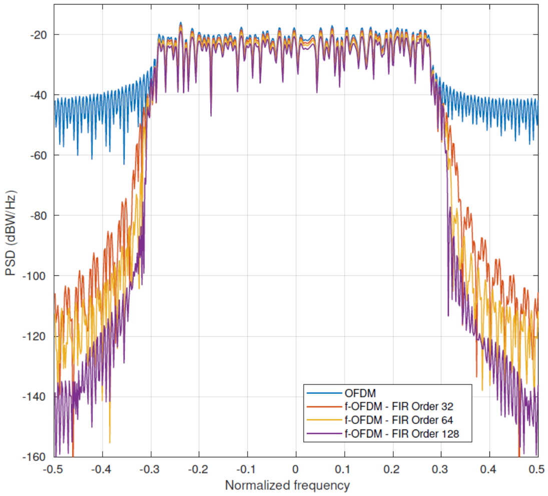


Figure: OFDM and f-OFDM PSD for filter orders 32, 64 and 128

Results and Discussion(Contd.)

Showing Filter's energy lies within the CP

- Figure 4 shows the base-band impulse response of the designed filter with bandwidth equal to $72 \times 15KHz + 2 \times N_e$.
- We can see that the main energy of the filters is confined within the main lobe,which expands to $2.084\mu s$.
- Therefore, the filter's energy stays within the CP(cyclic prefix) length(for normal CP length is $4.7\mu s$) and hence ISI(inter symbol interference) stays within tolerable levels.

Impulse response of the designed filter

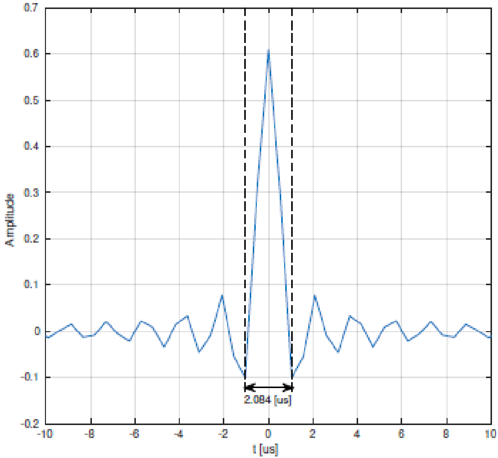
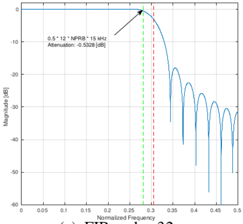


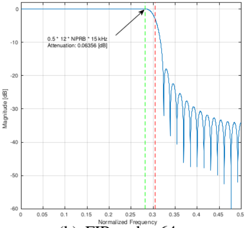
Figure: Impulse response of the designed filter for f-OFDM with bandwidth equal to $72 \times 15KHz + 2 \times N_e$.

Frequency responses of the designed filters for f-OFDM



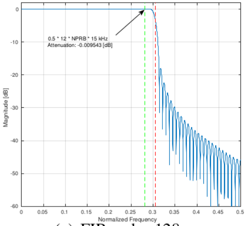
(a) FIR order 32.

(a)



(b) FIR order 64.

(b)



(c) FIR order 128.

(c)

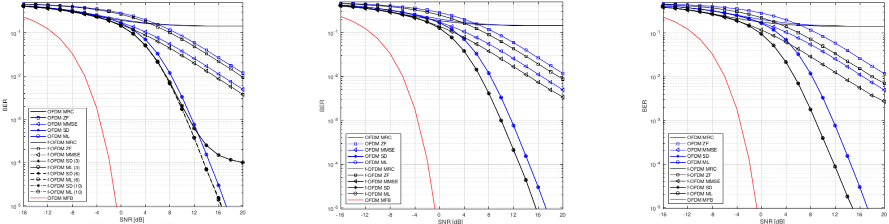
Figure: Frequency responses of the designed filters for f-OFDM having filter orders 32 (a), 64 (b), 128 (c).

Results and Discussion(Contd.)

Attenuation and 3dB cutoff frequency

- The figure 5 shows the 3 dB cutoff frequency (red-dashed lines) of the filters, which, as designed, happens at half of the useful bandwidth plus the excess bandwidth(N_e). *i.e.* $108/2$ MHz $+3 \times 15$KHZ $= 584$KHz.
- The 128 order filter shows a steeper transition,which results in lesser interference and hence a better frequency localization when compared with OFDM.
- As the filter order increases ,the subcarriers at the edges(green-dashed lines) of the symbol are less effected by attenuation.

BER evaluations



(a) FIR order 32. (b) FIR order 64. (c) FIR order 128.

(a) (b) (c)

Figure: BER performance for MIMO OFDM versus MIMO f-OFDM detection with filter orders 32 (a), 64 (b), 128 (c)

Results and Discussion(Contd.)

Comparing BER and MIMO detector performances

- In the figure 6, we present the Bit Error Rate(BER) evaluation,which is taken as average over all subcarriers carrying data.
- For better comparison we also add the MFB(Matched Filter Bound) to the graph, which is also known as perfect interference-cancellation bound.
- It can be seen that the BER of f-OFDM is lower compared to OFDM and it further decreases with increasing filter order.
- Hence,we see that f-OFDM with SD and ML detectors approaches MFB faster as filter order increases.
- It is important to note that SD and ML show similar performance though SD has lesser complexity than ML.

Results and Discussion(Contd.)

Disadvantage of f-OFDM and solution

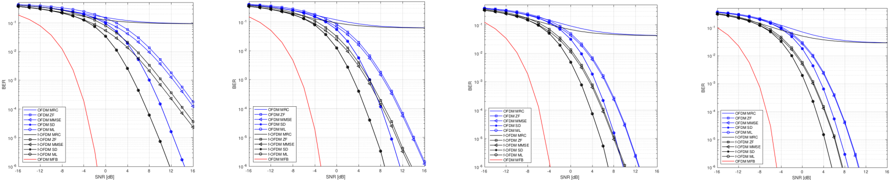
- It is also important to notice that for a filter order of 32 and $N_e = 3$ the BER for SD and ML detectors reaches a BER floor of approximately 10^{-4} for SNR greater than 12 dB.
- From there, f-OFDM behaves worse than the OFDM with SD and ML detection.
- This is due to, the subcarries at the edges are heavily affected by filter's poor performance at the edges(*i.e.*attenuation becomes noticeable).
- In order to validate our assumption, we also show the BER evaluations for excess bandwidth,N_e,of 3 and 10 subcarriers.This makes the edges flatter and therefore we do not see any unusual curve.

Results and Discussion(Contd.)

Effect of number of antennas at Base Station

- In figure 7 we see the BER performance of the detectors approaches MFB with increase in the number of antennas at the Base Station(BS).
- These results clearly prove that the interference caused by users transmitting at closely separated adjacent channels can be reduced by having a BS equipped with a large number of antennas.

Effect of number of Base Station antennas



(a) $M = 6$. (b) $M = 8$. (c) $M = 10$. (d) $M = 12$.

(a) (b) (c) (d)

Figure: BER performance for MIMO OFDM versus MIMO f-OFDM detection,filter order 128,number of antennas,M

Results and Discussion(Contd.)

Drawback of f-OFDM

- With increase in PAPR(Peak to average power ratio), the amplification becomes a problem.
- In figure 8,we assess the PAPR by a single carrier,in both OFDM and f-OFDM. Here , we measure the CCDF(Complementary Cumulative Distribution Frequency) for each of the modulations.
- We observe that the probability of the power of the OFDM and f-OFDM modulated signals being more than 3 dB above its average power level is higher than for a QAM modulated signal.
- Although f-OFDM reduces OOBE,it presents as a drawback, a PAPR that is higher than that for OFDM which still increases with increase in filter order.

CCDF

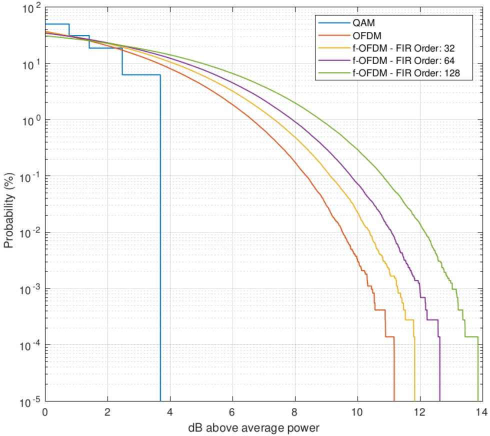


Figure: CCDF comparison of single-carrier and OFDM/f-OFDM modulation schemes.

Conclusion

- In this paper, we assessed the interference among adjacent signals in a MIMO system with OFDM and f-OFDM.
- The MIMO system performance was analysed by BER evaluations using detectors.
- Our analysis conclude that f-OFDM equipped systems perform better when power amplification factor is not an issue.Given this condition, f-OFDM acts as an excellent candidate for future generations of wireless communications.
- Therefore, f-OFDM systems allow closer frequency coexistence of devices, which increases the spectral efficiency, as the distance among adjacent channels can be decreased.