Performance Evaluation of FBMC Compared to OFDM by Simulation with Matlab

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***Abstract* – This paper evaluates the performances of FBMC as compared to OFDM in a simulation environment. Multicarrier techniques have been very influential in the development of wireless communication technologies especially Orthogonal Frequency-Division Multiplexing (OFDM), mainly deployed in new networks generation such as 4G, 802.11x, and DVB. Even though OFDM is more widespread than the other multiple sharing techniques, the technology presents some shortcomings in some special applications that are more efficiently addressed with the use of Filter Bank Multicarrier (FBMC). This paper performs a comparative analysis of OFDM and FBMC based on power spectral density, prototype filter, bandwidth efficiency and latency through simulation with Matlab software. Results showed that FBMC outperformed OFDM in many capacities and it should therefore be perceived as a promising technology for future emerging networks.**

Index Terms* – *OFDM, FBMC, Matlab, Wireless communication, 4G

I. INTRODUCTION

Wireless Communications continues to witness aggressive advances everyday [1]–[6] , motivated by the voracious customer request for bandwidth, speed and connectivity everywhere. Though several emerging technologies have enabled fair sharing of limited resources, the trend is unstoppable with newer technologies that improve quality of services. Several emerging technologies have been developed in telecommunications industry over the past years such as IoT (Internet of Things) with devices that was not used to be controlled over internet are now able to connect to internet and interact to one another in different ways. For instance, M2M machine to machine communications, carrier-grade Wi-Fi, and many others technologies. One of the most admirable technology upcoming is 5G (from Fifth Generation) New Radio, promising speeds 10 times faster than the previous 4G LTE [7]–[11]. 5G equally promises download speeds of up to 20 Gbps and very low latency that will improve significantly live streaming and broadcasting industries as well as allow for significant gains in IoT, M2M [12]–[16].

The development of those technologies as well as the immense number of users and devices request for high data rate, speed and bandwidth have raised massive attention on multicarrier modulation techniques for which the rationale is to split the main serial bit stream into several distinct parallel sub-streams and then modulate them on several different narrowband subcarriers of different frequencies. The carrier signals which are orthogonal to each other, are next added together for transmission. At the receiving end, they are divided and demodulate to recover the original bit stream.

Multicarrier modulation techniques are very beneficial with the possibility of increasing bandwidth, accommodating various fading channels and are less sensitive to interference compared to single carrier system.

Multicarrier modulation contributes massively in the development of wired and wireless systems, like xDSL (Digital Subscriber Line), DVB (Digital Video Broadcasting) and 4G LTE. However it is important to note that this technique existed long ago and was first used in military HF radios in the 1960s. There are various types of multicarrier modulation techniques. Some of the most broadly implememted include the followings:

- Orthogonal Frequency-Division Multiplexing (OFDM): It is potentially the most popular scheme of multicarrier modulation technologies. It employs many narrow-spaced orthogonal carriers with different frequencies to modulate the bit stream. Owing to their orthogonality property and the use of Cyclic Prefix (CP), they are less prone to interference [17]–[22].
- Generalized Frequency Division Multiplexing (GFDM): this scheme is a bit similar to OFDM but unlike OFDM, it employs narrow-spaced non-orthogonal carrier signals instead, and offers flexible pulse shaping. It is more suitable for applications such as Machine-to-Machine communications.
- Filter Bank Multicarrier Modulation (FBMC): It is a particular type of multicarrier modulation scheme that uses Offset Quadrature Amplitude Modulation (OQAM) instead of QAM and a specific pulse shaping filter called Isotropic Orthogonal Transform Algorithm (IOTA) in the digital signal processing side of the system [23]–[26]. This scheme offers good time and frequency localization properties ensuring the elimination of inter-symbol and inter-carrier interferences without the need of cyclic prefix used in OFDM. It is an evolution of OFDM

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OFDM has been probably the most successfully deployed technology in recent wired and wireless technologies such as XDSL, 802.11, 4G, etc. In OFDM every user is attributed a group of subcarriers. Synchronization is required at the receiver to avoid inter-carrier interference (ICI) between the users' carrier signals. This synchronization is however not required at the transmitter side, making OFDM more efficient with regard to the downlink. Several subcarriers are sent from the same transmitter (base station) and can then be easily synchronized. They subcarriers experience the same impairments like Doppler frequency shift before arriving at each receiver. Nevertheless, in the uplink, synchronization is almost negligible while several users can send signals independently. Practically, in uplink, ideal synchronization of an OFDM system might be nearly impossible, so extra signal processing is needed to reduce interference between the different transmitters' signals. These requirements cause more complexity in OFDM receivers.

Furthermore, OFDM performs poorly in a cognitive radio situation when primary users (no cognitive nodes) and secondary users (cognitive nodes) send signals independently and might operate under different standards. In this case filtering mechanisms are important to identify and divide the primary and secondary users' signals. In such systems, OFDM is not appropriate because the filters used for its carrier signals at the transmit and receive ends, have large side lobes resulting to high leakage of signals power. Although solutions such as Filtered OFDM, proposed to tackle the problem of side lobes and CP OFDM with the use of Cyclic Prefix to eliminate ISI and ICI, OFDM scheme is still not performing effectively to satisfaction.

All those shortcomings of OFDM technique are overcome by one important MCM technique called Filter Bank Multicarrier (FBMC) providing much better spectral shaping of subcarriers compared to that of OFDM systems using different design of prototype filters with small side lobes. The absence of CP and the use of Offset Quadrature Amplitude Modulation (OQAM) allow to use efficiently the full capacity of the transmission bandwidth.

The goal of this article is to conduct a performance analysis of the two multicarrier schemes, OFDM and FBMC under different environments and highlight the merits of the best for emerging technologies.

The performances comparison is based on Power Spectral Density (PSD), bandwidth efficiency, computational complexity regarding the magnitude responses, magnitude responses of the prototype filters and latency.

The research paper is structured as such. Section 1 is the introduction of the study. In section 2 an overview of OFDM and FBMC is briefly described, emphasizing the differences between them supported by their respective block diagrams, section 3 deals with the analysis of the simulations performed through MATLAB comparing the two systems performances with regards to the power spectral density, bandwidth efficiency, computational complexity regarding the magnitude response, the magnitude responses of the prototype filters of the two schemes and latency. Finally section 4 draws the conclusion of the study

II. OVERVIEW OF OFDM AND FBMC MULTICARRIER TECHNIQUES

In this section, the basic concepts behind two multicarrier techniques and their structures are introduced.

A. OFDM

Orthogonal Frequency-Division Multiplexing (OFDM) is a technique commonly applied in many wireless communication systems and telecommunication standards. It is a digital modulation technique by which a single data stream is broken into several sub streams and modulated on several distinct narrowband carrier signals at different frequencies to reduce interference and crosstalk.

In OFDM techniques, carrier signals of different frequencies are overlapping with very narrow space between them, and the orthogonality is achieved between the different carrier signals. The serial input bit stream is broken into parallel data sub-streams through a serial-to-parallel (S/P) converter. The parallel data streams pass through an Inverse Fast Fourier Transform (IFFT) block that transforms the frequency domain data streams into time domain sequence data streams. Cyclic Prefix (CP) is used to eliminate Inter-symbol Interference (ISI) among the OFDM symbol time sequences. The cyclic prefix is actually the copy of the last part of the symbol which is put at the beginning of the next symbol and must be greater than the network maximum delay to avoid inter-symbol interference caused by many phenomena such as multipath, reflection, etc. The cyclic prefix acts as a buffer or guard band to reduce ISI between OFDM signals. The digital signal obtained is converted into analogue signal by Digital-to-Analogue converter (D/A) for transmission.

At the receiving side, the signal is reconverted into digital signal by Analogue-to-Digital (A/D) converter and passes through the Fast Fourier Transform (FFT) block to transform the time domain digital data streams into frequency domain data streams after removing the CP. The output of the FFT block being parallel sub-streams are converted to serial bit stream before moving through a QAM demodulator to regain the original signal as it was originally transmitted.

OFDM scheme actually decomposes the wideband channel into a group of a narrowband orthogonal carrier signals with different modulated symbols over each carrier signals.

It is broadly implemented because of its numerous benefits such as:

- Orthogonality of subcarriers, they are independent to each other.
- Narrow-spaced orthogonal carrier signals divide the available bandwidth into numbers of narrow sub-bands

• Possibility of Adaptive modulation schemes over the subcarrier bands to augment bandwidth effectiveness and transmission rate.

OFDM have some disadvantages such as:

• Decrease of spectrum effectiveness because of the use of CP

• High spectral leakage because of the rectangular windowing used by the filters

• Interference between non-synchronized neighbouring signal bands.

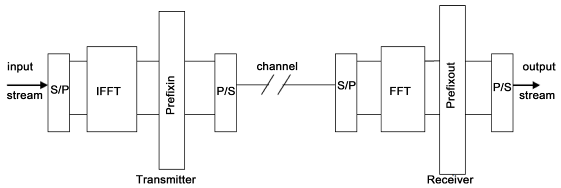

Fig 1: OFDM system diagram

B. FBMC

FBMC scheme is able to tackle the flaws of OFDM by adding generalized pulse shaping filters that offer a good time and frequency localization properties. FBMC system has more spectral containment and offers more optimization in terms of radio resources utilization as CP is no more required.

FBMC system uses filterbanks [24], [25] on the transmitter and receiver side. The filterbanks consist of an array of many filters that processes many input signals to produce the outputs.

The filter bank at the transmitter side is a synthesis filter bank and the one at the receiver side is an analysis filter bank. The input bitstream is first converted from serial to parallel multiple substreams and then introduced in the synthesis filter bank, converted back to serial bitstream after going out of synthesis bank.

On the receiver side, the bit stream is converted from serial to parallel form by the serial-to-parallel converter and moves into the analysis filter bank. The output of the analysis filter bank being parallel bitstream is converted to serial bitstream as it was originally by the parallel-to-serial converter. The pair Synthesis-Analysis filter banks is called Transmulitplexer (TMUX) and it is deployed in multicarrier communication systems.

FBMC can be considered as an evolved CP-OFDM. In FBMC the carrier signals are filtered independently unlike in OFDM where the entire band is filtered. The filters used for the carrier signals are very narrow, so time constants are required for better performances. Strangely, the time constant is fourfold that of basic multicarrier symbol length causing overlapping in time of the single symbols. To solve this problem, Offset QAM is used as the modulation scheme to ensure orthogonality.

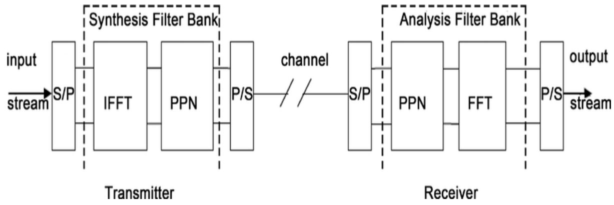

Fig 2: FBMC system

The main processing blocks of the FBMC transmultiplexer (TMUX) consists of OQAM pre-processing, synthesis filter bank, the analysis filter bank and the OQAM post-processing.

FBMC transmultiplexer system transmits OQAM symbols instead of QAM symbols. There exist two ways of implementations of FBMC, the frequency spreading filter bank multicarrier (FS-FBMC) and the poly-phase network filter bank multicarrier (PPN-FBMC). PPN-FBMC reduces the high complexity caused by the extra filtering operations at the transmitter and receiver.

The prototype filters used are highly frequency selective filters with almost no out of band leakage. With this prototype filters, the filter bank is obtained with frequency shifts, the subcarriers with odd or even index are not overlapped. Only the neighbor subcarriers have influences in a certain subcarrier. Hence a user can use only odd or even subcarriers for communication with QAM symbols. Then by using only alternate subcarriers, the bit rate decreases by half as half of the capacity is unused. Orthogonality is required for neighboring subchannels to use the full capacity. This orthogonality is performed by Offset Quadrature Amplitude Modulation. OQAM staggered the in-phase and quadrature by half a symbol period. OQAM is very important in the regeneration of the signal.

In each sub-channel either real part or imaginary part is transmitted avoiding interference between neighboring subchannels. FFT is then performed at twice the rate to maintain the bit rate high.

Figure 3 below depicts the symbols mapping of QAM and OQAM

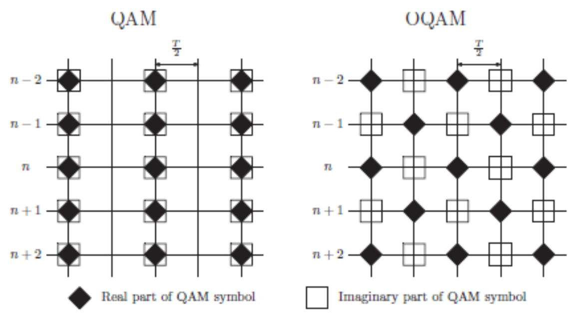

Fig 3: OFDM (QAM) and FBMC (OQAM) symbols mapping on carriers

At the transmitter side of FBMC, after the serial-to-parallel conversion, the OQAM symbols are sent through the IFFT block. The output symbols are treated with prototype filter before transmission.

The symbol generation is achieved when the prototype filter processes each frame. The output of IFFT, is duplicated and multiplied by the impulse response of the prototype filter. The filtered frames obtained are shifted with half symbol duration one by one obtaining the final transmitting signal. Because of the shift the total length of the transmitting signal is extended.

At the receiving end of FBMC system, the signal is broken into frames and the prototype filter is applied to each frame by multiplying the frames by the impulse response of the prototype filter. The symbol duplicated at the transmitting side is reformed and summed up back to one symbol as it was originally. The symbol passes through the FFT block frame by frame to recreate the OAQM symbol.

C. Comparison of bandwidth efficiency

Let the time spacing for transmitting one QAM symbol (2 PAM) is T_{QAM} and the frequency spacing for transmitting one QAM symbol as FQAM. The bandwidth efficiency is defined as:

$$\gamma = 1 / T_{QAM} F_{QAM}$$

Let designate one symbol duration as T, and assuming OFDM with CP, F_{QAM} as subcarrier spacing 1/T, and $T_{QAM} = T+T_{CP}$ where T_{CP} is the CP duration. In FBMC, $\mathbf{F_{QAM}}$ is subcarrier spacing 1/T and $T_{QAM} = T$ is symbol duration. Hence OFDM with CP is less bandwidth efficiency than FBMC.

- **Latency**

Let the sample duration $T_s = T / L$. In OFDM, latency is caused by serial to parallel conversion (S/P) and parallel to serial conversion (P/S) as well as CP. The latency due to S/P and P/S is $LT_s = T$.

Hence the total latency for OFDM is:

$$\tau_{OFDM} = T+T_{CP}$$

In FBMC, latency is caused by prototype filter which is $(L_p\text{-}1) = KT$ and also by OQAM modulation (T/2), S/P and P/S conversion pair, and filtering. Hence the total latency is:

$$\tau_{FBMC} = T/2 + T + KT = (k+1.5)T.$$

FBMC technique has higher delay than OFDM, it seems to be a disadvantage but it is able to meet the total latency requirements of many emerging technologies.

FBMC system has as main advantages:

- Spectral efficiency due to non-utilization of cyclic prefix
- Filters are used to remove the side-lobes spread out of the sub-carriers sides
- Much better usage of the available capacity and higher data rate
- FBMC can be implemented without synchronization of mobile user nodes signals

The major differences between OFDM and FBMC are outlined in the table below.

PROPERTY	OFDM	FBMC
CP Extension	Use of CP reduces bandwidth efficiency	Absence of CP improves the bandwidth efficiency
Side lobes	Large side lobes	Low side lobes
Synchronization	Required synchronization at the receiver for correct detection and multiple access interference (MAI) cancellation	Because of the good frequency localization of subcarriers, MAI is eliminated
Doppler effect	Highly Sensitive to the carrier frequency offset	Les sensitive. Then good performance with important number of users mobile
MIMO systems	High flexibility in MIMO techniques	flexibility is limited
Computational complexity	Less complexity	More complexity
latency	Lower latency	Higher latency, due to the complexity

Table I: Major differences between OFDM and FBMC

D. Simulations Analysis

The analysis provides the comparison between FBMC and OFDM by the means of simulation upon MATLAB. With M the number of subcarriers or subchannels and K the overlapping factor

- **Subchannels**

In FBMC each subchannel is filtered individually by well-shaped prototype filters. Hence the waveform of the subchannels are well shaped and has very low side lobes compared to OFDM where all the subchannels are filterd together through one prototype filter. Then the subchannels in FBMC have good spectral containment resulting the narrow band interference between them.

As shown in the figures below figure 4 and 6, the distance between the main lobe and the side lobes with FBMC subchannels is greater compared to those of OFDM in figure 5 and 7 Making FBMC subchannels more efficient with less interference between the subchannels, the side lobes also decay quicker compared to those of OFDM.

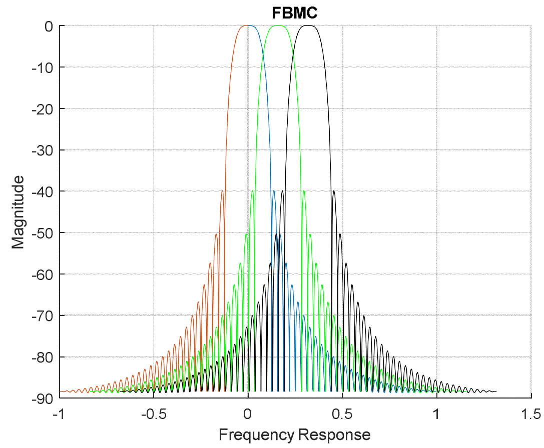

Fig 6: FBMC sub channels M=16 K=4

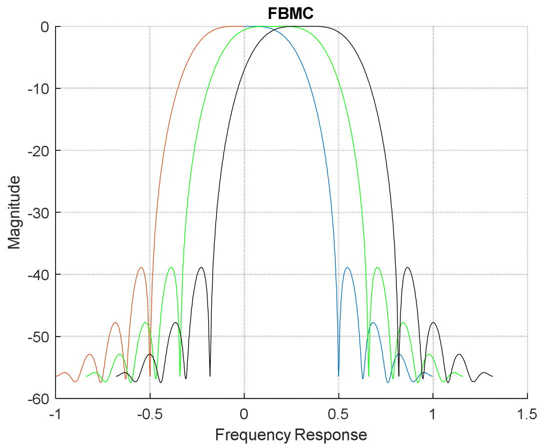

Fig 4: FBMC sub channels M=8 K=2

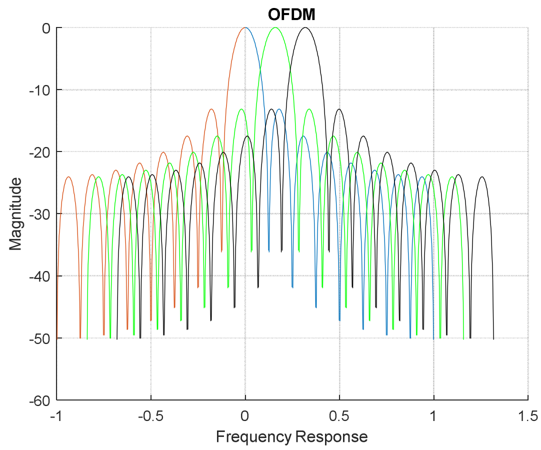

Fig 7: OFDM sub channels M=16 K=4

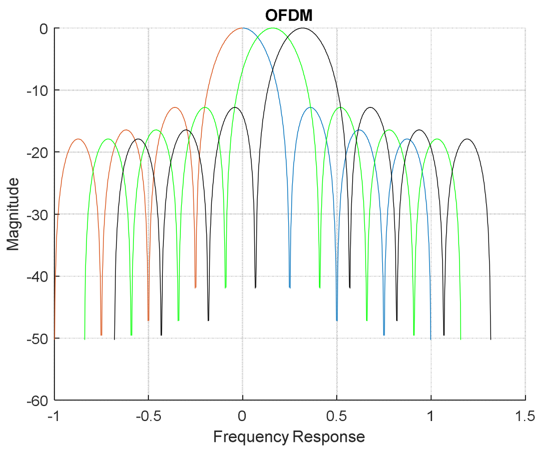

Fig 5: OFDM sub channels M=8 K=2

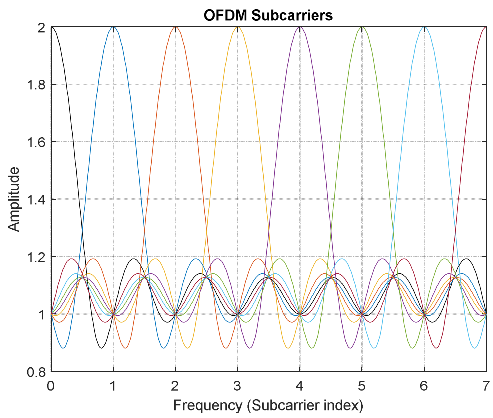

Fig 8: sensitivity of OFDM sub carriers with carrier frequency offset (CFO) M=8

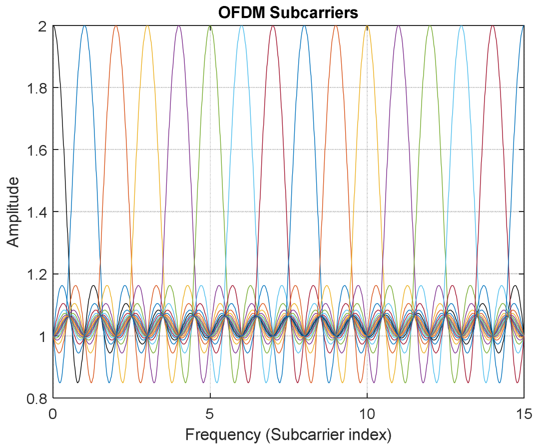

Fig 9: sensitivity of OFDM sub carriers with carrier frequency offset (CFO) M=16

- **Power spectral density**

The power spectral density of FBMC transmit signal is plotted and compared with OFDM system without CP using the full occupied band.as shown in figures 9, 11 and 13 FBMC has low out-of-band leakage and lesser side lobes compared to OFDM in figure 8, 10 and 12. FBMC provides higher spectral efficiency allowing a higher utilization of the spectrum. Hence it is more efficient and advantageous compared to OFDM; however, the per carrier filtering and OQAM processing delay is larger.

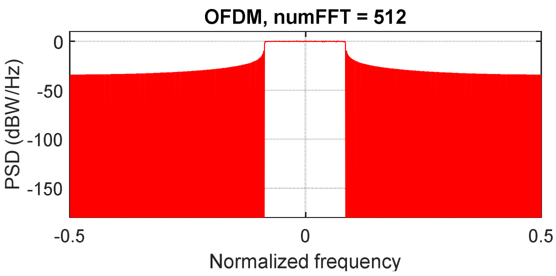

Fig 10: OFDM Power spectral density

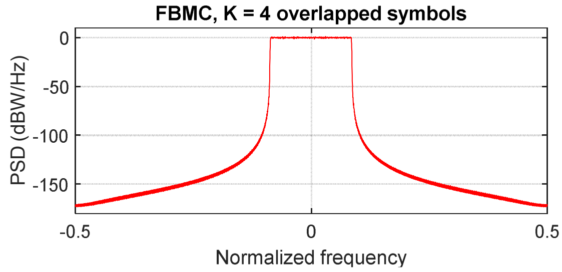

Fig 11: FBMC Power spectral density for K=4

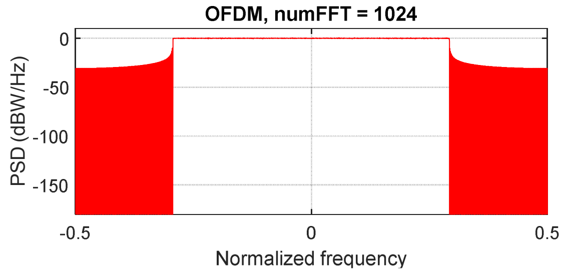

Fig 12: OFDM Power spectral density

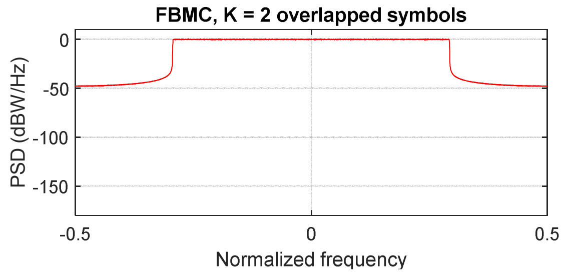

Fig 13: FBMC Power spectral density for k=2

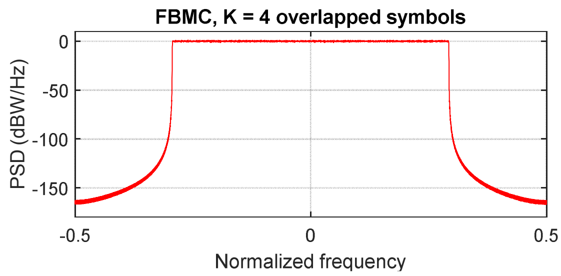

Fig 14: OFDM Power spectral density

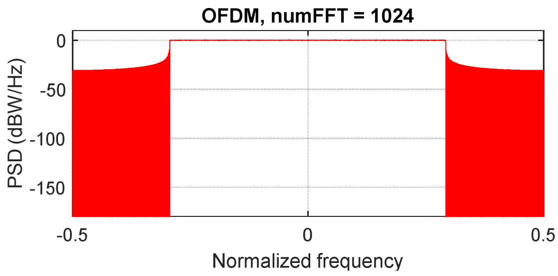

Fig 15: OFDM Power spectral density for K=4

- **Computational complexity in terms of magnitude responses**

The filter bank computational complexity is assessed by determining the number of real multiplications for each complex symbol and supplement necessary to compute new length output sequence. The analysis is focused on real multiplications because the adders are cheaper to implement than the multipliers.
In OFDM we have:

$C_{FFT/IFFT} = M\,[\log_2(M) - 3] + 4$

In FBMC, the number of real multiplications for each complex symbol is given by:

$C_{SFB} = \log_2(M/2) - 3 + 4*K$, and
$C_{AFB} = 2[\log_2(M/2) - 3] + 4*K$
Where SFB is Synthesis Filter Bank and AFB Analysis Filter Bank

Complexity is less in OFDM than FBMC due to the exchange of IFFT/FFT modules by the filter banks in FBMC. The number of real multiplications with respect to the number of carrier signals in case of OFDM and FBMC have been analyzed. Moreover, FBMC uses poly-phase (PPN) implementations which increases the complexity compared to FBMC without poly-phase (PPN) implementation.

- **Magnitude response of prototype filter**

The prototype filter implemented in OFDM is a rectangular window filter while in FBMC the prototype filter is designed with the Nyquist pulse shaping principle causing the reduction of the spectral leakage issue in OFDM and further reducing ICI and ISI. The comparison of the magnitude response of prototype filters deployed in OFDM and FBMC is depicted in simulation results below.
There is a rapid deterioration across the sidebands in frequency response of FBMC systems for overlapping factor K= 2, 4 and 8, meaning that there is a large isolation between the subchannels which reduces ISI and ICI. Whilst with OFDM the isolation between subchannels is short increasing the likelihood of ICI.

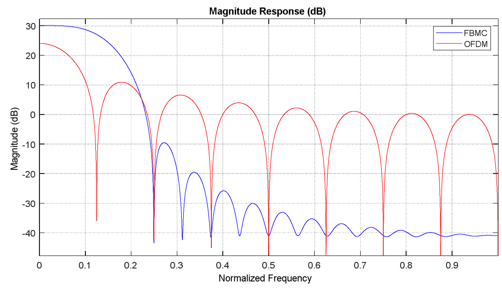

Fig 16: OFDM and FBMC magnitude response of prototype filters for M=16 K=2

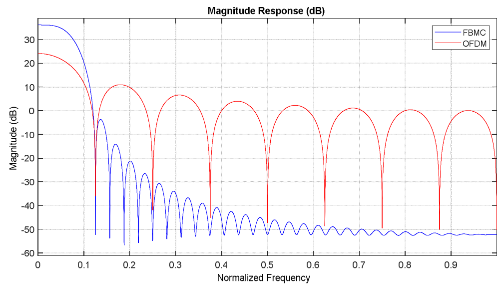

Fig 17: OFDM and FBMC magnitude response of prototype filters for M=16 K=4

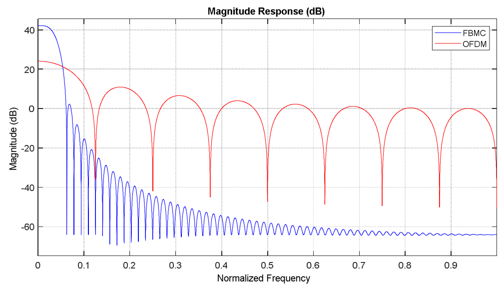

Fig 18: OFDM and FBMC magnitude response of prototype filters M=16 K=8

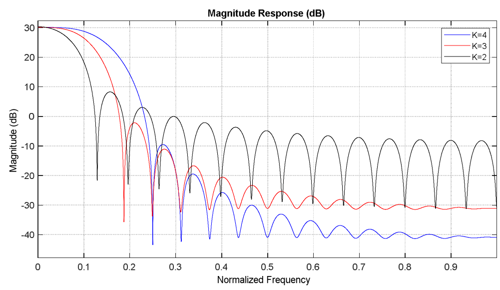

Fig 19-A: Filter response for K=2, K=3, K=4

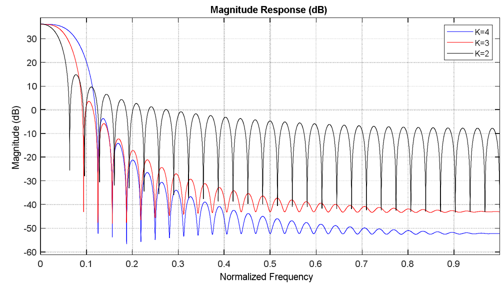

Fig 19-B: Filter response for K=2, K=3, K=4

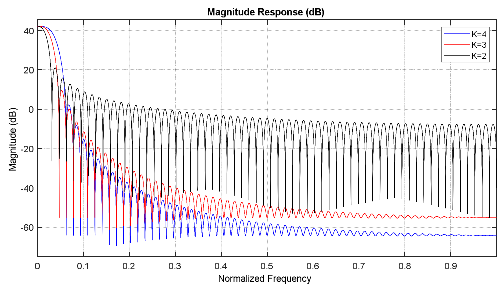

Fig 19-C: Filter response for K=2, K=3, K=4

E. CONCLUSION

In summary, this paper presented a comparative analysis of OFDM and FBMC through on simulations with MATLAB software. The performance comparison has been performed based on waveforms of subchannels, bandwidth efficiency, power spectral density, computational complexity with regards to magnitude response of prototype filters and the latency.

The different simulations have demonstrated that FBMC technique is able to address and remove the flaws of OFDM and its performances are much better than OFDM where the waveforms of subchannels cause high spectral leakage and increase the likelihood of ICI or ISI and also the use of CP reducing the spectral efficiency making it not appropriate for cognitive radio and multicarrier uplink whilst in FBMC spectral efficiency is achieved as well as very low interference. Thus FBMC is the best option for future emerging technologies.

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