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Implementation of 5G FBMC PHYDYAS Prototype Filter

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Abstract

There are a lot of problems in the 4G (Orthogonal Frequency Division Multiplexing - OFDM) system, and the most prominent of those problems is using a big number of cyclic prefixes (CPs) at the header of each symbol in each sub-carrier, which used to reduce the multipath effects, that increasing the symbols length therefore not exploiting the channel capacity and increasing the latency.

In this paper, we introduced a description of the next 5G (Filter Bank Multi-Carrier- FBMC) system that reducing the problems in the 4G (OFDM) system, and that is through using the banks of filter instead of using the CPs.

In this work, we implemented the response of prototype filter called (PHYsical layer for DYnamic spectrum AccesS and cognitive radio – PHYDYAS) that used in 5G (FBMC) using the MATLAB.

Keywords: 4G, OFDM, 5G, FBMC, PHYDYAS.

INTRODUCTION

In the last century, specifically in 1980, the 1G mobile analogue technology was started and changed the life of the world, which introduce the voice calling services [1].

In 1990, the 2G mobile digital technology was introduced in Finland that called GSM, which introduce the international voice calling services [1]. In 2.5G, called GPRS, the system is used both packet and circuit switching domains [2]. In 2.75G, named EDGE which introduced at 1999 in USA, the system is used 8PSK encoding and improved the data rate [2].

The 3G mobile technology was introduced in 2000 by the IMT–2000. The 1 Mbps rate services of mobile TV, video calls and others are introduced in the 3G system [1].

The 4G, introduced since 2010, is the wireless cellular standard, which uses IMT-advanced technology [1].

The 5G technology, expected to introduce in 2020, will provide larger data rate to be compatible with the future internet of things (IoT) applications [3]. The 5G system will use many technologies to achieve the major user requirements [4]. Table 1 shows a general description of the main generations.

OVERVIEW FIFTH GENERATION (5G)

An overview of the coming 5G technology is introduced in this section, where it will be essential technology in the world because it will provide higher data rate to users in modern age. The presents technologies cannot achieve the future IoT services [5, 6].

The coming 5G technology will connect billions of devices with each other and support more than 9 billion subscribers, and these subscribers will be able to share their data in any time and from anywhere [1].

The 5G system will need to many upgrades for the devices and equipment in comparison with the present and past generations [1]. And the main 5G system requirements are [7]:

- 10 times increased battery life.
- 10 –100 more times data rate.
- 5 times lower delay (or latency).
- 10 –100 times higher devices connecting.
- 1000 times higher mobile data volumes.

5G KEY ENABLING

The 5G will support higher speeds with quality of experience (QoE) and connect massive numbers of devices together [8].

In the coming 5G system, a millimeter-wave (mm-Wave) will be addressed to achieve the massively higher capacity, which provide bandwidth of 10 times more than 4G bandwidth. The 5G will support the MIMO system to achieve the advanced small cell, which experiences small inter user & cell interferences and therefore get higher throughput. The FBMC technique is one of many new multiple access techniques that will use in 5G [8].

Adaptive modulation techniques such as OQAM can be used to achieve the Gbps. Multi-RAT will aid to increase the bandwidth. New topologies and device to device (D2D) technology will participate in reducing the latency of network [1].

OFDM (4G) AND FBMC (5G) DESCRIPTION

To reduce the multipath effects, the multi carrier modulation technique (MCM) is used, which divided the full bandwidth into small bands.

In the present 4G techniques, the MCM is represented by OFDM technique. OFDM introduced good synchronization because of using the rectangular pulse shape called ICI, also the OFDM can implement practically based on the FFT. The OFDMA is a current multiple access technique used in the 4G LTE system [9].

Because of the higher intensity toward synchronization errors and Doppler effect, the MCM technique can use filter banks with OQAM mapping to improve the spectral efficiency and the channel capacity [10], and this technique called Filter Bank Multi Carrier (FBMC) which will be used in the coming 5G system. The main OFDM and FBMC transceivers block diagram is shown in Fig. 1.

Table 1: General Description of the Main Generations.

Main Features / Main Generations		Launch	Main Standard	System	Main Technology	Data Rate (bps)	Main Service
0G		1946	MTS	Analog	FM-SSB	-	Wireless Communicate
0.5G		1970	ARP	Analog	FM-SSB	-	Remote Communicate
1G		1980	AMPS	Analog	FDMA	-	Mobile Communicate
2nd G	2G	1990	GSM	Digital	TDMA	9.6 K	International Communicate
		1993	CDMA One	Digital	CDMA	9.6 K	Coded Communicate
	2.5G	1997	GPRS	Digital	FDMA/TDMA	35 to 171 k	SMS
	2.75G	1999	EDGE	Digital	FDMA/TDMA	120 to 384 K	MMS
3rd G	3G	2000	UMTS	Digital	WCDMA	384 K to 1 M	Multimedia
	3.5G	2007	HSDPA	Digital	WCDMA	1 to 2 M	Internet
	3.75G	2009	HSUPA	Digital	WCDMA	2 to 3 M	High Data
4G		2010	WIMAX	Digital	OFDM	3 to 10 M	Higher Data / Speed
		2013	LTE	Digital	OFDM	20 to 100 M	Internet Higher Data / Speed
5G		2020	WWWW	Digital	FBMC (Candidate)	1 to 100 G	Internet of Things (IoT)

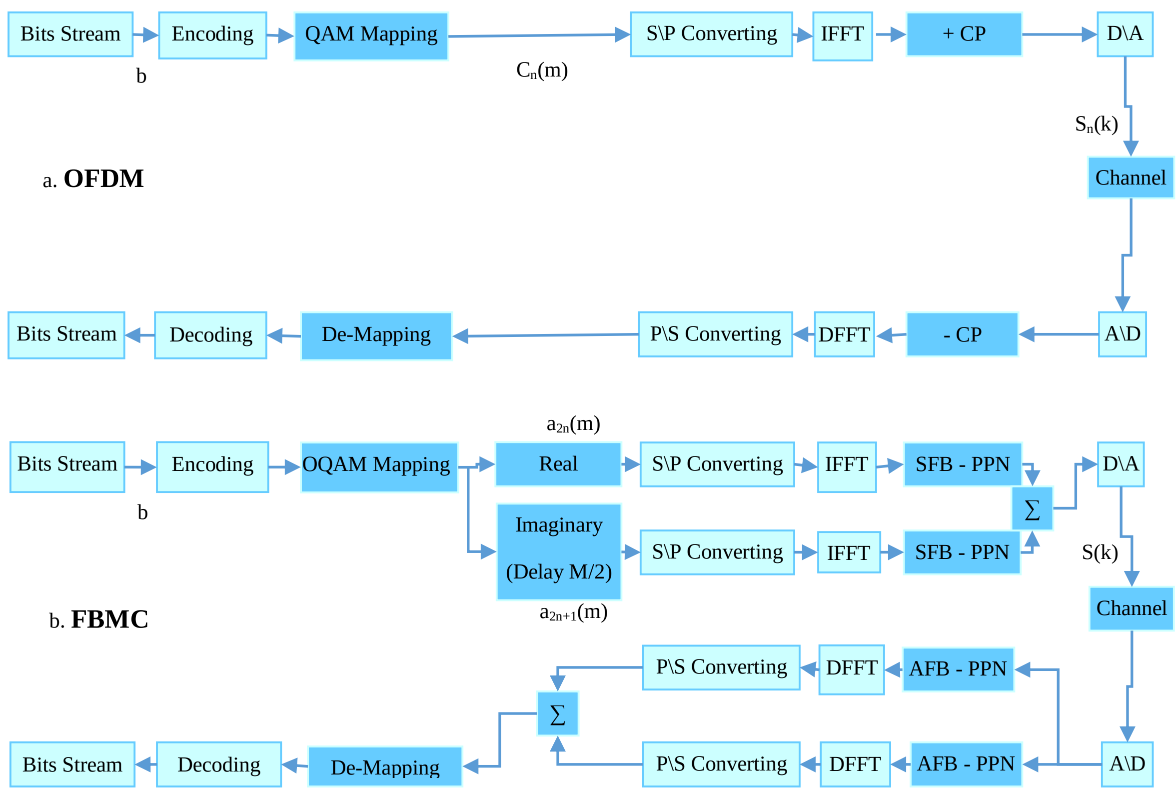

Figure 1: General block diagram of OFDM and FBMC transceivers.

A. *OFDM*

As shown in Fig. 1.a, the high data bit rate stream is splitting into lower bit rate stream at the encoding stage, then it is converting to complex form at the QAM mapping stage ((*I*) and (*Q*) of *cn(m)*).

The complex data is converting from serial to parallel at the S\P stage, then applying the M inverse FFT (IFFT) length at the IFFT stage to make the orthogonal case between the sub-carriers and the unused sub-carriers are filled by zero. Discrete time domain of the baseband OFDM modulation is [9]:

$$s(k) = \sum_{n=-\infty}^{+\infty} \prod(k - nM) \sum_{m=0}^{M-1} c_n(m) e^{\frac{j2\pi mk}{M}}, \quad (1)$$

Where M is the sub-carriers, $c_{n(m)}$ is the QAM data, and $\prod$ is the function [9]:

$$\prod = \begin{cases} 1 \; if \; 0 \leq k \leq M-1, \\ 0 \qquad elsewhere. \end{cases} \quad (2)$$

In frequency domain, the $Sinc$ function is represented each carrier, and the expression can be written as [9]:

$$s_n(k) = \sum_{m=0}^{M-1} c_n(m) e^{\frac{j2\pi mk}{M}}, \quad (3)$$

To avoid the delay spread in multipath channel effects, a CP is used at OFDM symbol header to reduce the ISI, but these CPs cause cost in the channel bandwidth and spectral efficiency.

The CP insertion is a process of taking a copy of the end symbol part and inserting it at the beginning of symbol as guard interval between the symbols [11] (it is must be more than the channel delay spread [12]).

Then at (D\A) stage, the data is converting to a continuous signal and sending it through the channel. At the destination side, the reverse processes are performing.

B. *FBMC*

As shown in Fig. 1.b, the FBMC modulation differs from OFDM in three stages. First, it reduces the ICI and ISI by using OQAM mapper with properly filter. Where the OQAM introduced a time domain offset of $M/2$ samples of $c_{n(m)}$ components, which are the $I(a_2 n(m))$ and the $Q(a_2 n + 1(m))$ [9].

Second, it uses the poly phase network (PPN) as filter processing after IFFT stage. This filter processing introduced a good localization in time (reduces ISI) and frequency (reduces ICI) [9]. For optimal localization in both time and frequency, the PHYDYAS prototype filter is used [13], also the raised cosine filter can be used for the same purpose through a roll off factor but it, theoretically, needs to very long filter length [13]. In this work, we preferred the PHYDYAS because of its better localization and simpler equalization at transmitter and receiver.

Third, the combination of the PHYDYAS filtering and the OQAM modulation processes introduces orthogonality without using CPs, and so improved the spectral efficiency and the channel capacity [9]. Discrete time domain of baseband FBMC/OQAM is [9]:

$$s(k) = \sum_{n=-\infty}^{+\infty} p\left(k - n\frac{M}{2}\right) \sum_{m=0}^{M-1} a_n(m) j^{n+m} e^{j\frac{2}{\pi}m\left(k-\frac{L-1}{2}\right)}, \quad (4)$$

Where $e^{-j\frac{2\pi}{M}m\frac{L-1}{2}}$ is a phase component.

The filter bank is a synthesize and analyze multicarrier signals. In the presented work, PPN-FBMC model is chosen, where it introduced low complexity at the transmitter and receiver. Fig. 2, shows simple PPN transceiver.

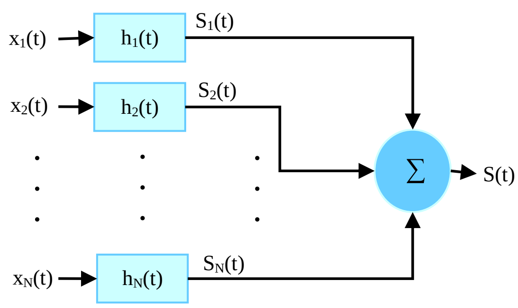

Figure 2.a: Transmitter synthesis PPN filter bank (SFB).

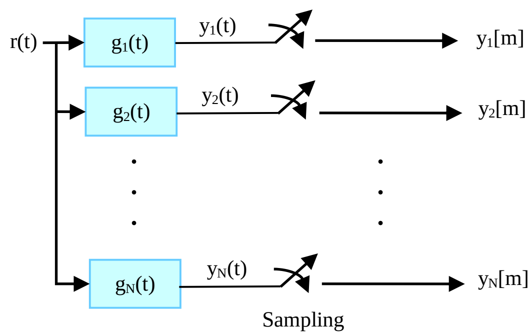

Figure 2.b: Receiver analyze PPN filter bank (AFB).

In this work, the PPN PHYDYAS filter is used with the overlapping factor (*K = 2, 3, 4*). Table 2 shows the coefficients of PHYDYAS [13].

Table 2: Coefficients of Phydyas In Frequency Domain.

K	$P_{\pm k}$	P±0	P±1	P±2	P±3
2		1	√2/2	-	-
3		1	0.911438	0.411438	-
4		1	0.971960	√2/2	0.235147

And they satisfy the equation:

$$\frac{1}{K} \sum_{k=-K+1}^{K-1} |P_k|^2 = 1, \quad (5)$$

Where P_k is coefficient impulse response, K is overlapping filter, k is subcarrier index.

The M subcarriers frequency response equation is:

$$P(f) = \sum_{k=-(K-1)}^{K-1} P_k \frac{\sin(\pi(f-\frac{k}{MK})MK)}{MK \sin(\pi(f-\frac{k}{MK}))}, \quad (6)$$

The impulse response of prototype filter after the IFFT processing is:

$$p[L] = 1 + 2 \sum_{k=1}^{K-1}(-1)^k P_k \cos(\frac{2\pi k}{MK}L), \quad (7)$$

$p[0] = 0$,: Used to select the odd coefficients numbers.

Where L is the prototype filter length ((M×K)-1). To get the full channel capacity, the OQAM implements the orthogonality between the sub channels.

RESULTS

In this work, we implemented the response of prototype filter called PHYDYAS that used in FBMC (5G) system by using the MATLAB software.

We implemented three different prototype filter lengths ((M×K)-1) of overlapping factors (K) *2, 3, & 4*; and *16* sub-carriers (M). Fig. 3, shows the PHYDYAS filter response with different lengths (K= *2, 3 & 4*) of one sub-carrier. Fig. 4, shows comparison for one FBMC & OFDM sub-carrier. Fig. 5, shows three OFDM sub-carriers. Fig. 6, shows three FBMC sub-carriers.

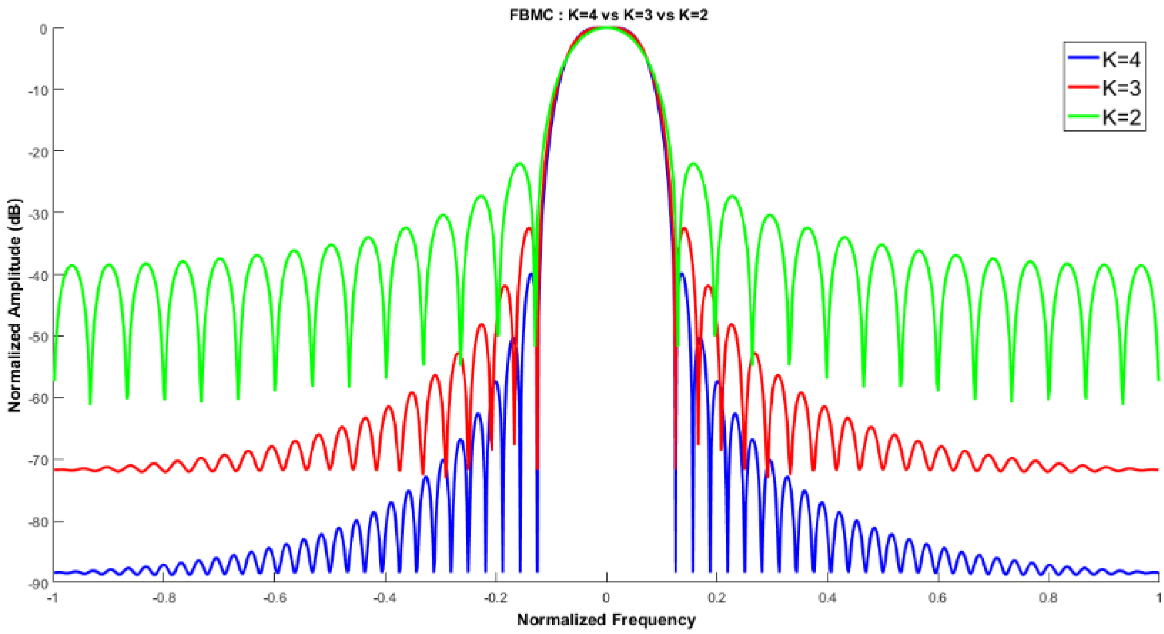

Figure 3: PHYDYAS filter response with different lengths.

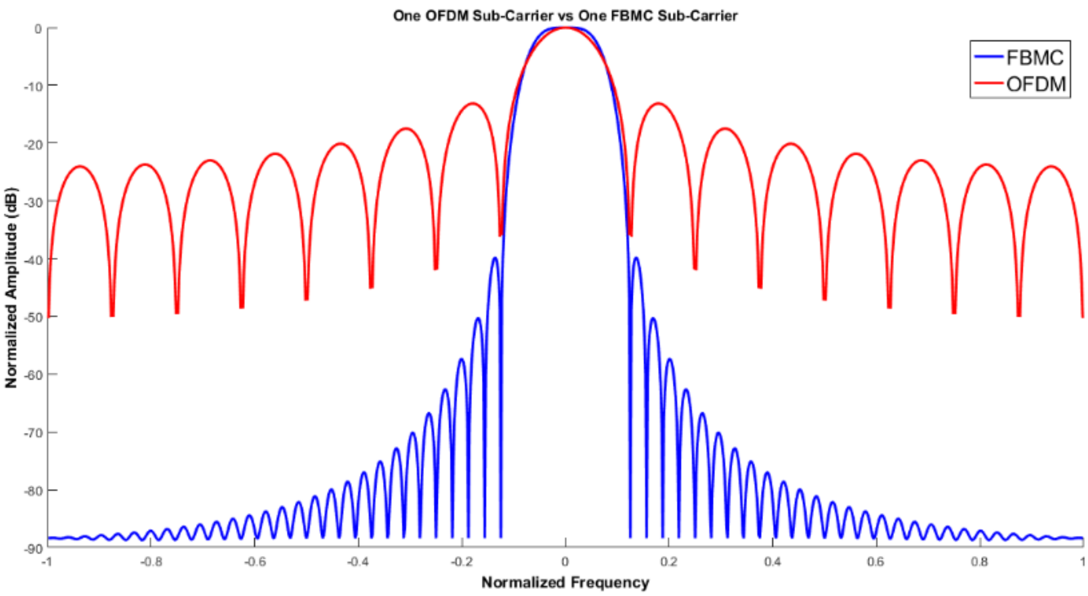

Figure 4: One FBMC sub-carrier and one OFDM sub-carrier.

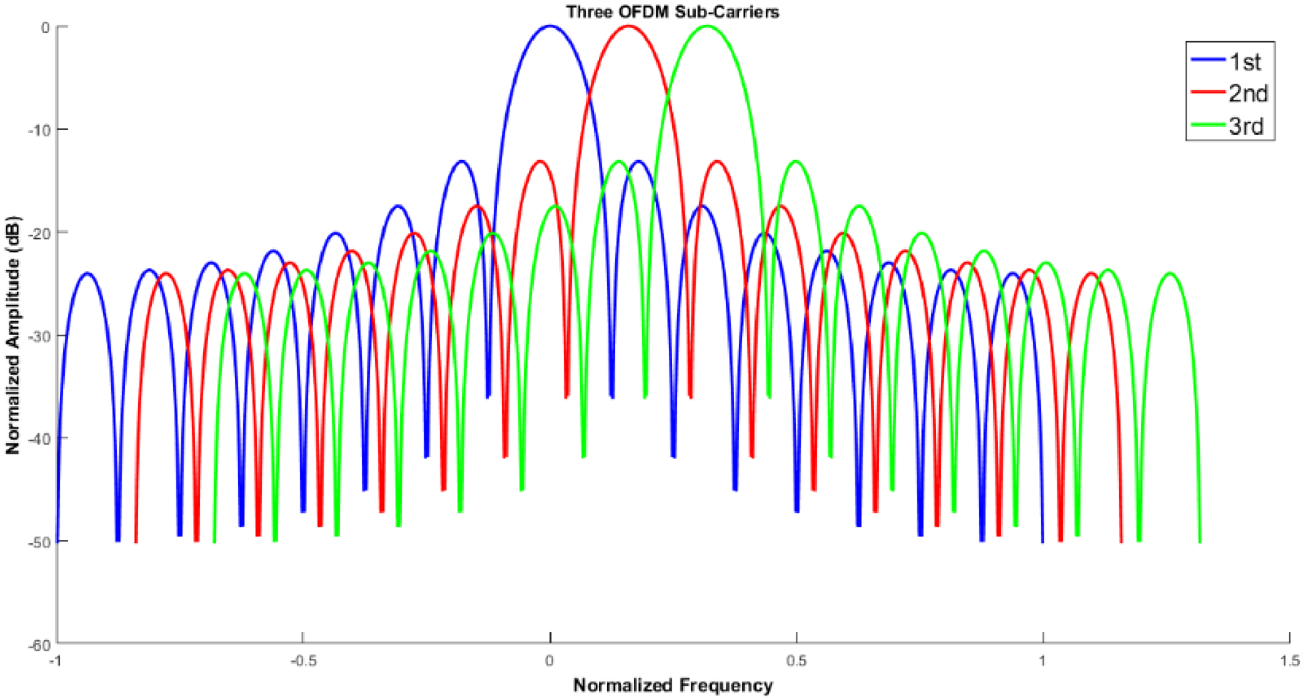

Figure 5: Three OFDM sub-carriers.

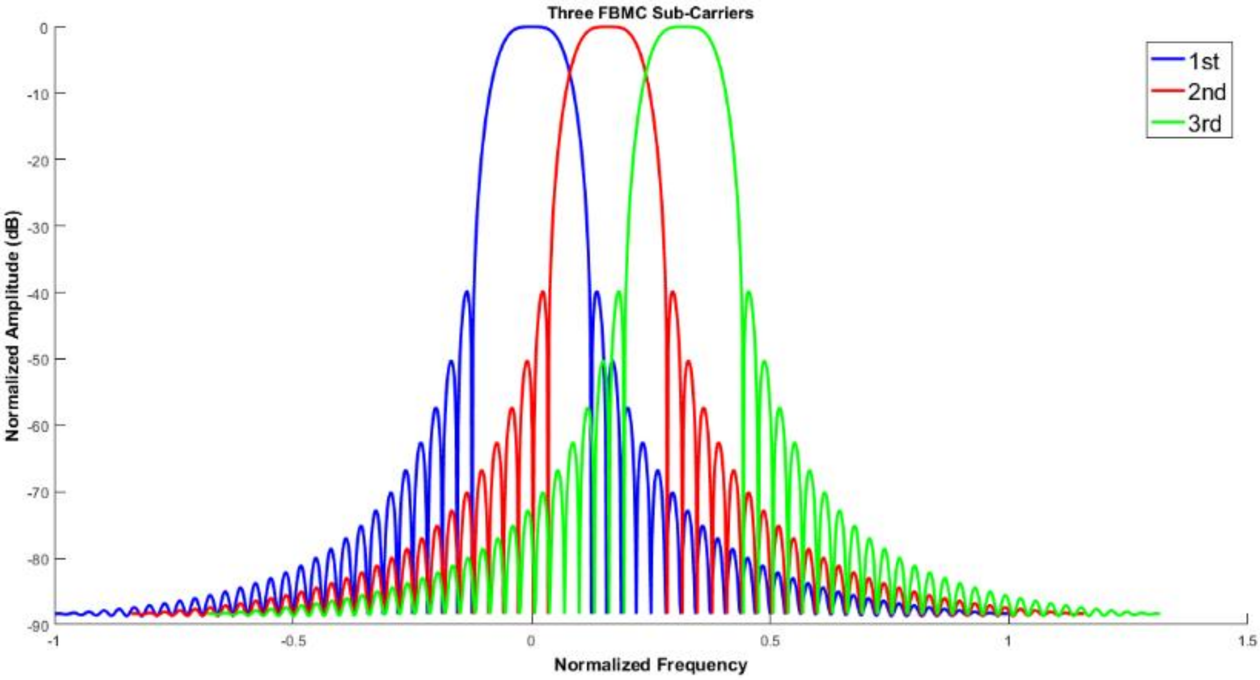

Figure 6: Three FBMC sub-carriers.

CONCLUSION

The objective of 5G (FBMC) system is to reduce the problems in the 4G (OFDM) system, and that is through using the banks of filter for each symbol instead of using the CPs at each symbol in each sub-carrier.

Thus by removing the CPs, we reducing the high sidelobes that causing high ISI, ICI, OOB, PAPR; and reducing the symbols length and therefore getting high exploitation of the channel.

We concluded that the PHYDYAS prototype filter length ($L=(MK)-1$) of overlapping factors ($K=4$) is introduced the best spectral efficiency.

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