On the Multiple Access Technique for 5G Wireless Networks

M. Saber, A. Nader, Mohamed E. Nasr

Abstract— The next generation of wireless networks (5G) aims to provide a high capacity, high data rate, while the available spectrum will remain the same, so it is important to search for a modulation technique capable of achieving the 5G requirements. Although, orthogonal division multiple access (OFDM) is the signaling method in (4G) provides a good performance it has many limitations make it not suitable for (5G) specifications. One of the candidate schemes is the Filter Bank Multi-Carrier with Offset Quadrature Amplitude Modulation (FBMC/OQAM), the use of FBMC with appropriate filter prototypes allows to obtain an almost negligible inter-symbol interference (ISI) and inter-carrier interference (ICI), and provides a better spectral efficiency. In this paper the drawbacks of OFDM and advantages of FBMC are explained. A comparison between the performance of OFDM system and FBMC system in terms of Signal to noise ratio (SNR), filter response, and Bit error rate (BER) is performed, and the FBMC architecture this been implemented using gate FPGA with new realization .

Index Terms— orthogonal division multiple access (OFDM) , Filter Bank Multi-Carrier with Offset Quadrature Amplitude Modulation (FBMC/OQAM), inter-symbol interference (ISI) .

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1 INTRODUCTION

THe future mobile technology (5G) is expected to meet the requirements of higher data rate (1-20 Gbps), and extra number of users, which requires more efficient use of the frequency spectrum, to fulfill with these new requirements several modulation schemes have been proposed. It is known that, OFDM is the most modulation technique in broadband wired and wireless systems [1]. OFDM Also used in the broad class of DSL standards and in the majority of wireless standards such as, variations of IEEE 802.11 and IEEE 802.16, 3GPP-LTE, and LTE-Advanced [2]. Unfortunately, OFDM has many drawbacks make it not suitable for the 5G specification, so it is important to search for other modulation technique for 5G technology.

One of the important candidates for 5G is Filter Bank Multicarrier (FBMC), it is a waveform technique which intends to improve the performance of the previous technique in use, OFDM [3-4-5]. The first developments for this technology date back to the 1960's when a bank of filters was used to process a parallel set of Pulse Amplitude Modulation (PAM) symbol sequences. However, only recently has the interest around it increased, due to its perceived higher computational complexity.

An FBMC waveform is obtained by the transmission of data through a filter bank, while in OFDM systems an IFFT coupled with Cyclic Prefixing (CP) is used, in FBMC this is replaced by a synthesis filterAs the name implies, FBMC is used for digital multicarrier modulation. The main benefits in the utilization of this type of modulation are the minimization of inter symbol interference (ISI) and inter carrier interference (ICI) that might be introduced when using channels with varying gain in their frequency band. This is possible because the use of multicarrier modulation eases the task of channel equalization, which is is used to diminish the effects of the ISI and ICI Another most important advantages of FBMC is its higher spectral efficiency, when compared with OFDM systems [6][7]. FBMC doesn't use CP so it increases this performance, as CP originates additional overhead and, as a consequence, a loss in bandwidth efficiency. Beside that, FBMC shows a severe reduction in out-of-band (OOB) leakage [8]. OOB leakage is the transmission of signals outside the designated frequency band and it plays a big part in the system's spectral efficiency. Having higher OOB leakage introduces the need for guard bands which are wasteful towards the spectrum use. Also, OFDM systems present strong side lobes in their frequency response, while FBMC has a lower side lope. Both FBMC and OFDM systems' frequency responses are shown in Fig. 1

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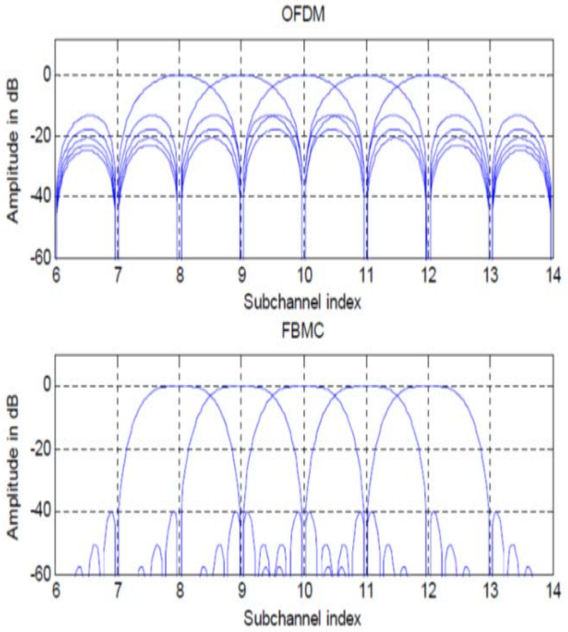

Fig. 1 FBMC and OFDM systems' frequency responses

As can be seen in this Fig. 1, side lobes in FBMC are considerably smaller than the ones obtained with OFDM [9-10]. In FBMC a subchannel only overlaps its adjacent subchannels, making it easier to achieve two independent multicarrier signals simply by leaving an empty subchannel between them. This result also helps to avoid inter carrier interference. The high selectivity and spectral containment of FBMC subchannels also contribute to achieving good resistance when faced with narrowband interference. It has been calculated that FBMC presents a 20% gain in spectral efficiency when compared to OFDM [11].The filter bank used in FBMC consists of a set of filters, that, when combined together, form the impulse response of the prototype filter. The choice of this prototype filter is one of the characteristics of FBMC which allows it to present better frequency containment. The prototype filter, parameterized by the overlapping factor (K), can be chosen in a way to achieve higher selectivity and low adjacent channel leakage. The use of long and well-shaped filters makes the non-adjacent subcarriers almost perfectly separated. This result varies with the filters' overlapping factor (K). As mentioned above, this result contributes to one of FBMC's most important characteristics, its high spectral efficiency by having the energy concentrated in the frequency range of a subcarrier the wasteful guard bands can be little to non-existent.FBMC's higher selectivity when compared with OFDM can easily be seen when analyzing the frequency response around a single subcarrier. This is represented in Fig .2.

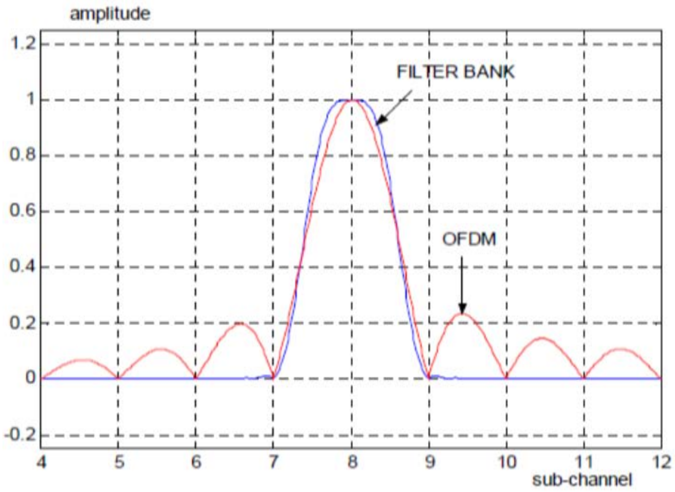

Fig. 2 Selectivity of FMBC and OFDM

From Fig. 2, it is possible to observe that OFDM exhibits ripples in the frequency domain, while FBMC's frequency response has little to no amplitude outside the desired frequency range. The use of near-perfect subcarrier filters also allows FBMC to avoid multiple access interference (MAI) without the need to perform synchronization. This is another result that helps FBMC stand out from OFDM, as in OFDM to achieve no MAI some cancellation is needed, which greatly increases its complexity [12-13].Our paper is organized as follows. After providing the comparison between FBMC and OFDM, section II shortly describes the FBMC/OQAM architecture and explain the operation of each block. Section IV presents a comparative analysis between OFDM and FBMC is in terms of SNR and BER, and also investigate the performance of FBMC system. Finally, section V presents the realization and implementation of FBMC architecture using FPGA.

2 SYSTEM ARCHITECTURE

FBMC's transceiver consists of serial to parallel converter, an initial modulation block, followed by a synthesis filter bank (SFB) and a parallel to serial conversion in the transmitter, while in the receiver it has serial to parallel followed by analysis filter bank (AFB), a demodulation block, and parallel to serial conversion as shown in Fig.3. Both SFB, and AFB are a filter bank with the same structure, but only simple differences will be explained next.

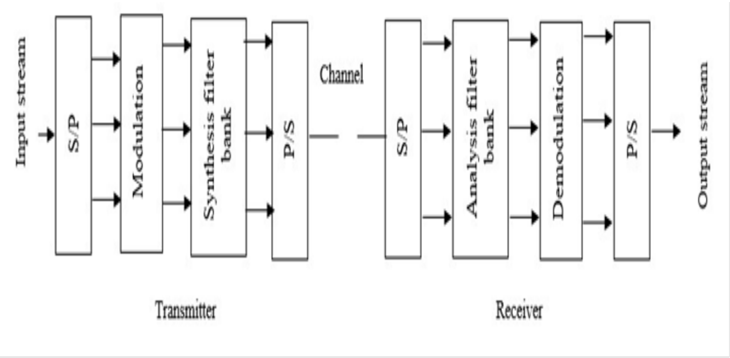

Fig. 3 FBMC generic system

2.1 OQAM Modulation

QAM as a modulation technique with FBMC leads to a lower spectral efficiency as orthogonally between subcarriers is obtained through a redu reduction in the frequency domain overlap. While OQAM technique, obtain orthogonally in the real domain only, which guarantees maximum spectral efficiency. The use of OQAM modulation also has the impact of doubling the processing rate of the system. As a consequence of its better spectral performance OQAM based FBMC implementations are considered as the baseline modulation for FBMC.OQAM modulation is done in a processing block which performs a complex-to-real conversion. In this operation the real and imaginary parts of a symbol $a_k(l)$ form two different new symbols $b_k(2l)$ and $b_k(2l+1)$ The resulting values are then multiplied by a complex sequence which can be obtained from the following expression:

$$\theta_k(n) = j^{k+n} \qquad (1)$$

Where k represents the subcarrier index with $k \in [0; M-1]$;n represents the time index at OQAM subsymbol rate.This leads to an alternation between purely real and imaginary values in subchannel signals. The corresponding architecture can be seen in Fig. 4. Besides k and n, which have already been defined in Eqn (1), l represents the time index at an OQAM symbol rate. After this pre-processing value is either purely real or imaginary .

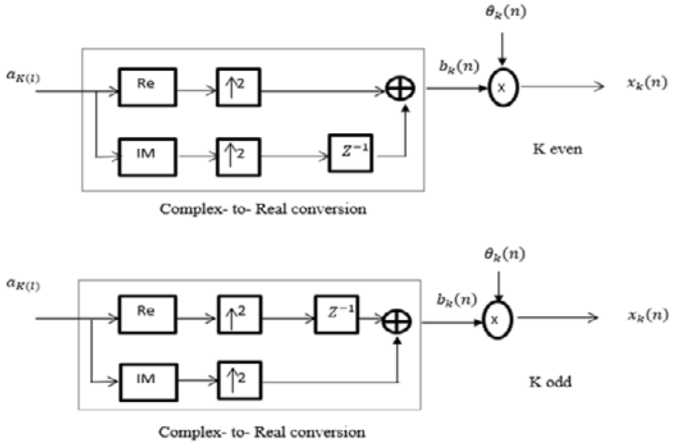

Fig. 4 OQAM preprocessing.

2.3 FILTER BANK

The filter bank is realized by using IFFT followed by polyphase network, it is called PPN-FBMC as shown in Fig. 5

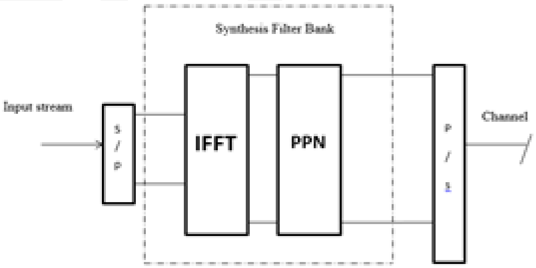

Fig. 5 PPN-FBMC architecture

In the PPN-FBMC, the input OQAM symbols are fed to an IFFT block with size N. The resulting data is then applied to a polyphase network (PPN); to obtain the final signal to be transmitted the parallel values output by the PPN are serialized and sent to the channel. The IFFT and PPN correspond to the system's synthesis filter bank [14]. PPN block used in this variety of FBMC implementations consists in a set of filters which, when combined, form the impulse response of a prototype filter which can be configured in such a way to achieve better localization in the frequency domain. The shape and length of the prototype filter will change the time and frequency domain localization.A direct form SFB consists of M up samplers and M synthesis filters, the input signals $X_k(z)$, where $k = 0,1, 2,\cdots,M-1$, are first up sampled by M/2 and then filtered with synthesis filters $G_k(z)$. The SFB output signal Y (z) is formed when all sub signals are added together as shown in Fig. 6.

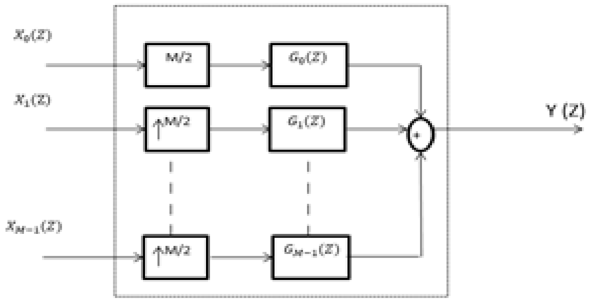

Fig. 6 SFB structure

A direct form AFB is constructed using M analysis filters and M down samplers. The input signal Y (z) is first filtered by analysis filters and these signals are then down sampled by a factor of M/2 to form output signals , as shown in Fig. 7

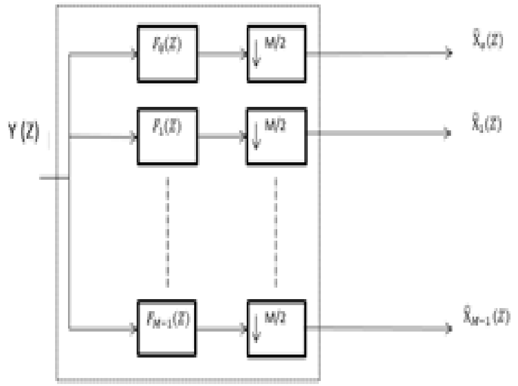

Fig. 7 AFB structure

The type of filter used in both SFB, and AFB is a finite impulse response (FIR) filter. Filters of this type have an impulse response of finite duration which lasts N+1 samples, N being the order of the filter, with its output being the result of a weighted sum of the input values. A standard implementation architecture of an FIR filter is shown in Fig. 8.

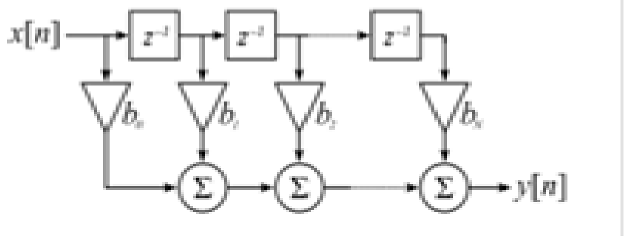

Fig. 8 Architecture of an FIR filter.

The filter banks have the following characteristics:

-The number of subchannels is even number, although it is common to use a power of 2, as it is one of the conditions for some efficient IFFT algorithms;

-The filter length should be given by one of the following equations:

L = KM L = KM+1 L = KM-1

Where L is the filter length, K the overlap factor and M the number of subcarriers used.

Having defined the values of L ,M, and K to design the prototype filter one can use the frequency sampling technique. This technique starts by obtaining L target values in the frequency domain and then obtaining the prototype filter coefficients using the following Eqn:

$$h(m) = 1 + 2\sum_{k=1}^{K-1}(-1)^k H\left(\frac{k}{L}\right)\cos\left(\frac{2\pi km}{L}\right) \qquad (2)$$

Table 1 provides a study of the impact of the overlap factor K on the transmission performance of the system such as ISI, and ICI.

TABLE 1
IMPACT OF K ON SYSTEM TRANSMISSION PERFORMANCE .

K	ISI	ICI
2	-45.1 dB	-30.2 dB
3	-53.3 dB	-43.9 dB
4	-67.8 dB	-68.7 dB

3 SIMULATION RESULTS

There are two types of simulations in this paper, the first type presents a comparison between performance of OFDM and FBMC for the same specification. While the second type of simulations presents an investigation of the performance of FBMC according to the change of specific parameters in FBMC architecture such as number of subcarriers, and overlapping factors.

3.1 OFDM Vs FBMC

1) **Power Spectral Density (PSD)**

A comparison between PSD of OFDM and PSD of FBMC is shown in Fig. 9 for the same subcarriers number (1024). According to Fig. 9, FBMC has lower side lobes. This leads to an advance in utilization of the spectrum. While OFDM has higher side lobes and out of band leakage. So, FBMC is more advantageous in comparison to OFDM by providing higher spectral efficiency.

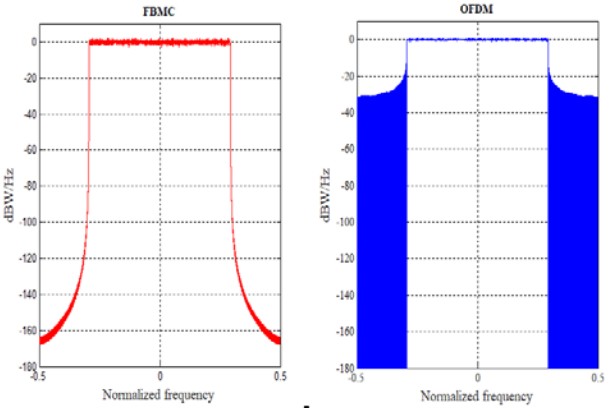

Fig. 9 PSD comparison.

2) Magnitude response

The main difference between FBMC and OFDM is the choice of the prototype filter. Such that OFDM uses a rectangular window filter and FBMC using a prototype filter designed with the Nyquist pulse shaping principle, which can reduce greatly the spectral leakage problem of OFDM. This results in negligible ICI and ISI. In Fig.10 the magnitude responses of prototype filters of FBMC and OFDM have been compared against the normalized frequency.

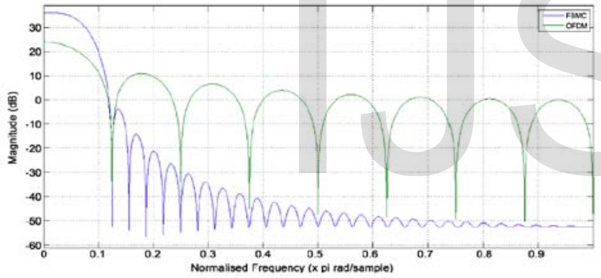

Fig. 10 Comparison of magnitude response of prototype filters of FBMC and OFDM

3) Bit error rate (BER)

In this simulation, we plot the BER for OFDM and FBMC. OFDM system has CP and modulation scheme is QAM, and number of subcarriers 2048, while FBMC is modulated with OQAM and no CP is used for the same subcarriers number. Fig.11 indicates that FBMC has lower BER for the range of SNR [0 : 5 dB].

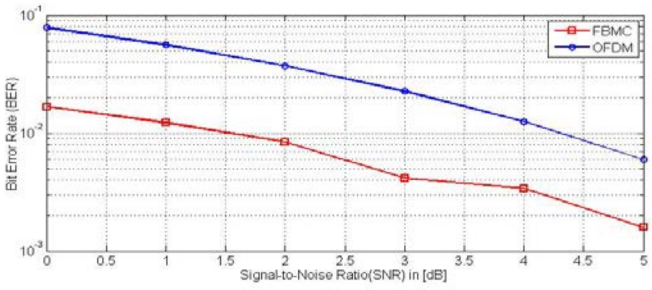

Fig. 11 Comparison of BER for FBMC, OFDM.

3.2 FBMC PERFORMANCE EVALUTION

To evaluate the performance of FBMC system, two important parameters are considered the first is overlap factor (K), while the second is BER with a number of subchannels (M). The value chosen for the overlap factor K is directly related to the achieved selectivity and as a consequence, the out-of-band leakage. In Fig. 12, it can be observed that as K decreases the out-of-band performance worsens, until a result similar to that of OFDM is seen.

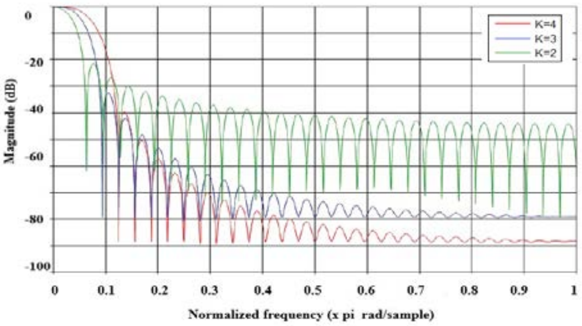

Fig. 12 FBMC’s spectral profile with different value of K

To investigate the BER of FBMC with different modulation schemes, a comparison between 16-PSK, 16-QAM, 16-OQAM has been done in Fig. 13, and it ensures that the expected results, that the OQAM provides the best BER compared to other modulation techniques.

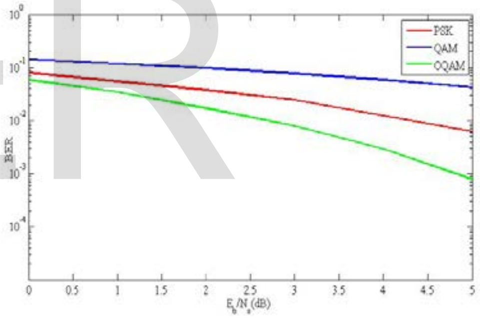

Fig. 13 BER of FBMC with different modulation schemes

4 IMPLEMENTATION OF FBMC

The FMBC architecture is realized using a Xilinx system generator tool which can generate VHDL code to describe the operation of FMBC transceiver. The VHDL code of the architecture is simulated using Modelsim tool to meet the required specifications. The architecture is implemented using Xilinx Spartan-6 XC6SLX45 FPGA board. The FBMC architecture is designed for 8 subscribers or channels, the channel sample rate is 200 kHz, the carrier separation of the transmitter spectrum is 200 kHz. The general specifications of the architecture are:

- Number of subscribers = 8.

- IFFT/FFT length: M =8 points.
- Overlap factor: K=4.
- Filter length: L= 32, with a pass band frequency 90 kHz and stop band frequency of 100 kHz.
- Channel sample rate = 200 KHz.
- Sample Rate= No. of subscribers X channel sample rate = 1.6 MHz..

Fig. 14 shows the top level model of FBMC transmitter architecture realized in the Xilinx system generator. The top level architecture consists of the following blocks: OQAM modulator, and Synthesis filter bank (SFB).

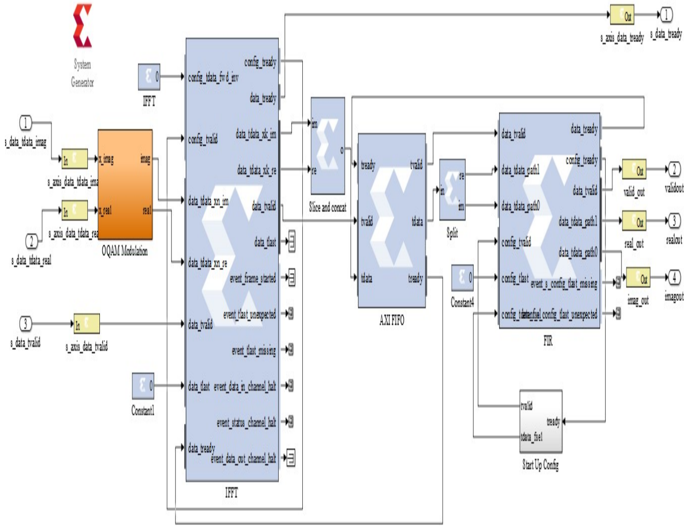

Fig.14 Top level FBMC transmitter architecture.

The input data source is complex sinusoidal samples for different 8 channels. The input samples are generated at the symbol rate, which is exactly 1.6 MHz. The OQAM modulator block is shown in Fig. 15, make time-frequency lattice from the input data complex symbols for channels at a doubled data rate.

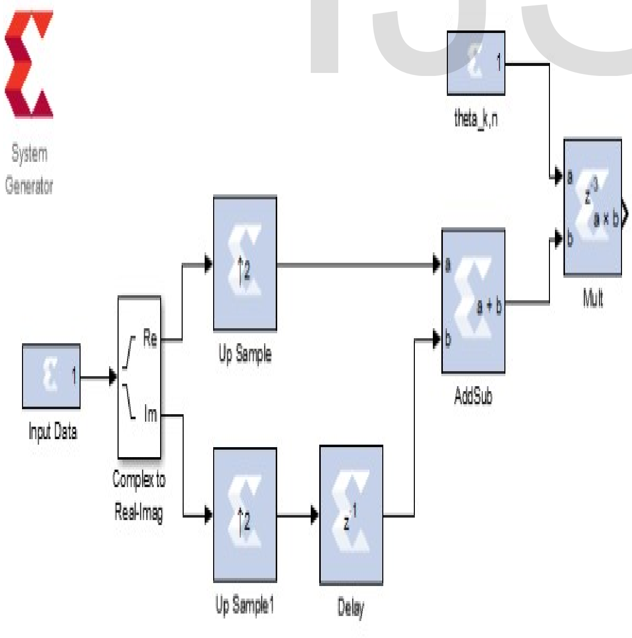

Fig.15 OQAM modulator architecture.

The filter bank realization based on polyphase filters. The SFB consist of IFFT block and polyphase filtering. The output is complex baseband at 8 times higher rate than an input symbol rate. The simulation of IFFT processor using Modelsim program is shown in Fig. 16. The output spectrum of the transmitter is shown in Fig. 17.

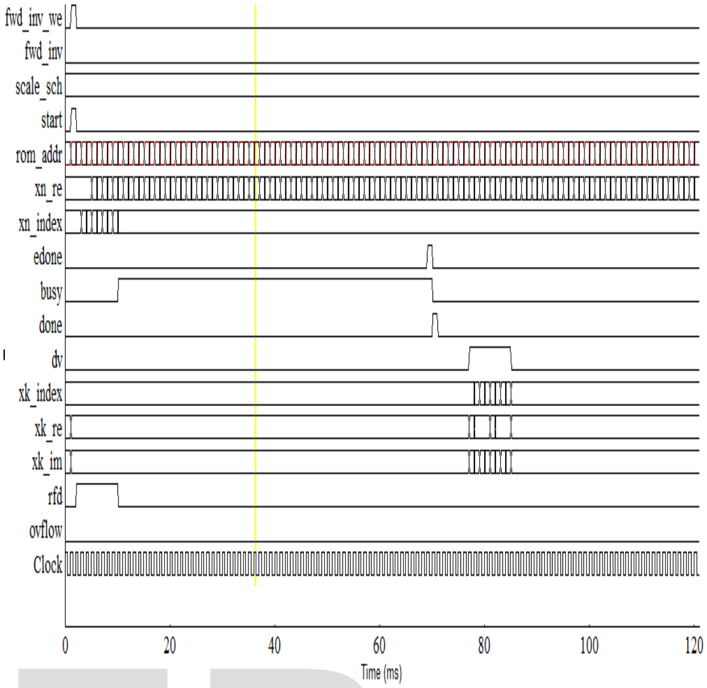

Fig. 16. Simulation for IFFT block.

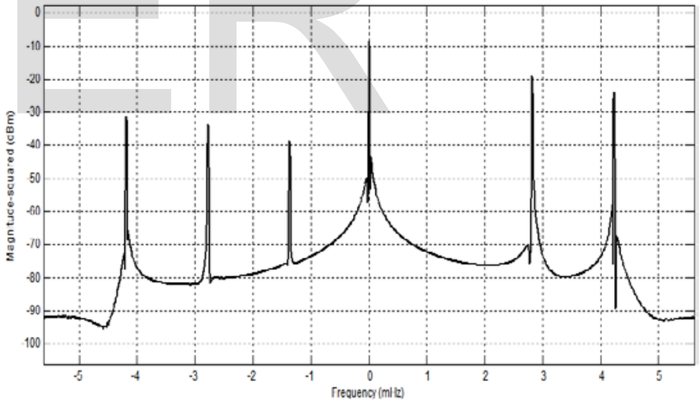

Fig. 17 FBMC' transmitter output spectrum.

The receiver of the architecture realized in Simulink is shown in Fig. 18. The analysis bank based on the polyphase realization demodulates the synthesized signal with almost perfect reconstruction, dividing it into 8 sub-channels. The outputs show up in the burst of the 8 symbols where every symbol belongs to one of 8 frequency sub-channels. The resources used in the implementation of FBMC transmitter and receiver are illustrated in Tables 2.

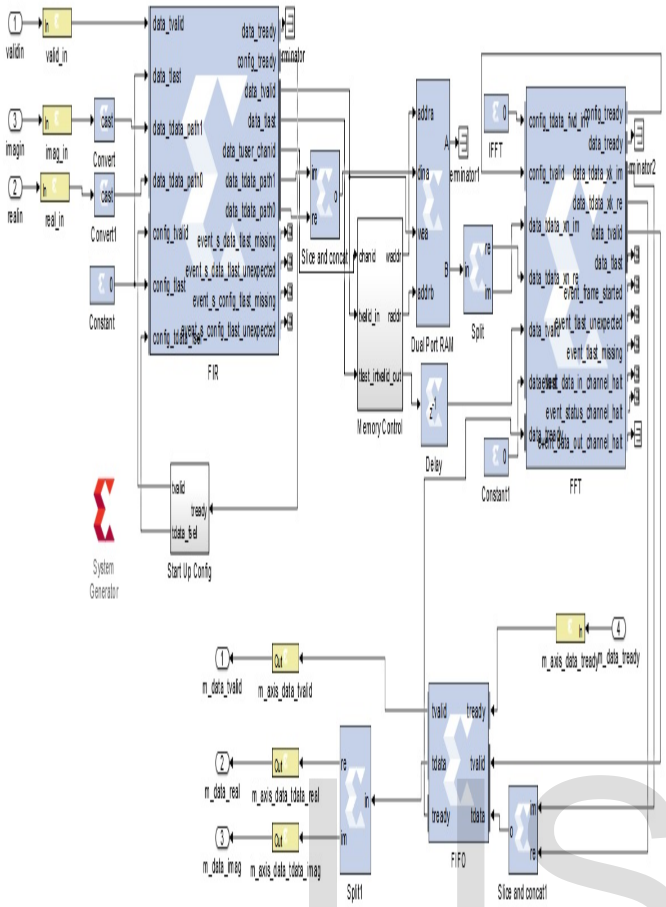

Fig. 18 FBMC' receiver architecture

TABLE 2
RESOURCES REPORT FOR THE IMPLEMENTATION OF FBMC ARCHITECTURE .

Resources	M=8	
	Transmitter	Receiver
No. of Slice Registers	300	340
No. of Slice LUTs	680	739
No. Of fully used LUT-FFs	420	505
Max. Clock	286 z	

5 CONCLUSION

In this paper, we present a comparison between structure, operation, the performance of OFDM and the candidate modulation technique (FBMC) for 5G networks. A different comparison simulations have been done between OFDM and FBMC such as PSD, magnitude response of prototype filter, and BER vs SNR. Also the performance of FBMC system is investigated through a simulation of the system with different number of subcarriers.

The FBMC architecture is implemented using Xilinx Spartan-6 FPGA board. All simulation results show that FBMC gives overall performance improvement compared to conventional OFDM for all the parameters considered, proving FBMC as an ideal candidate for future development in wireless communications.

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