A Review on FBMC: An Efficient Multicarrier Modulation System

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ABSTRACT
Multicarrier modulations attract a lot of attention among engineers and researchers working in the field of telecommunications. One specific form of multicarrier modulation referred to as OFDM has been the dominant technology for broadband multicarrier communications. Despite their many advantages, OFDM systems have a few, but important drawbacks. Filter bank multicarrier (FBMC) is an evolution with many advantages over the widespread OFDM multicarrier scheme. Filter banks are an evolved form of subband processing based on Fast Fourier Transforms and addressing some of its shortcomings, at the price of a somewhat increased implementation complexity. In this paper, a review of FBMC and its concept is presented, emphasizing its benefits over OFDM in applications such as Cognitive Radio(CR), Multiple access networks, TVWS, PLC and MIMO communication .

Keywords
Multicarrier modulation, OFDM, FBMC, OQAM, CMT, SMT, Cognitive Radio.

1. INTRODUCTION
Multicarrier modulation has marked its importance over the past several decades for the realization of broadband communication systems. Based on sending parallel streams of information in the frequency domain on different center frequencies, multicarrier modulation has exhibited its potential to transmit large amounts of data across a channel while improving the robustness of communication system against various impairments.

Among the existing multicarrier modulation systems, OFDM (orthogonal frequency division multiplexing) is the most widespread. OFDM has attracted a lot of attention because each subcarrier signal can be demodulated in the absence of inter carrier interference (ICI) and intersymbol interference (ISI) which is achieved by transmitting redundancy in the form of a cyclic prefix (CP). However, this is associated with the reduction in the spectral efficiency and also in certain applications such as cognitive radio and uplink of multicarrier systems, OFDM may be an undesirable solution[1]. One solution to this problem is to employ a multicarrier system referred to as FBMC[2].

In FBMC, a set of synthesis and analysis filters are designed such that they have both adequate spectral selectivity and bandwidth efficiency. Although each filter could be designed on an individual basis, a more efficient approach is to design a single prototype low pass filter and modulate it to several specified center frequencies to generate the synthesis and analysis filters $g^{(k)}(n)$ and $f^{(k)}(n)$, k = 0,……,N-1. Usually the filters are uniformly spaced, designed to be highly spectrally selective to minimize cross-talk with adjacent subcarriers, can either be odd stacked or even stacked; which implies, no center frequency at $\omega_0 = 0\frac{rad}{s}$ [3].

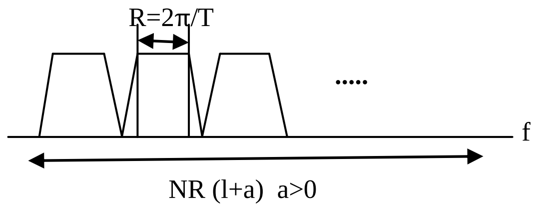
2. EVOLUTION OF FBMC TECHNIQUES
Prior to OFDM, the first multicarrier methods that were developed, were based on filter bank. The first proposal came from Chang in the 1960s, who presented the conditions required for signalling a parallel set of Pulse amplitude modulated (PAM) symbol sequences through a bank of overlapping vestigial side band (VSB) modulated filters[4]. Saltzberg extended the idea and showed how the Chang's method could be modified for transmission of Quadrature amplitude modulated (QAM) symbols[1]. In 1980s, Hiroshaki progressed more on FBMC and proposed an efficient polyphase implementation for the Saltzberg method[5]. The method proposed by Saltzberg is referred to as OFDM based on offset QAM or OFDM-OQAM. This method is also referred to as staggered modulated multitone (SMT).

In the 1990s, the advancements in digital subcarrier line (DSL) technology led to more work on two classes of FBMC communication systems, namely filtered multitone (FMT) and discrete wavelet multitone (DWMT) modulation[6]. More recently, in [7] it has been shown that DWMT is essentially using cosine modulated filter banks. Therefore, DWMT was renamed to cosine modulated multitone (CMT).

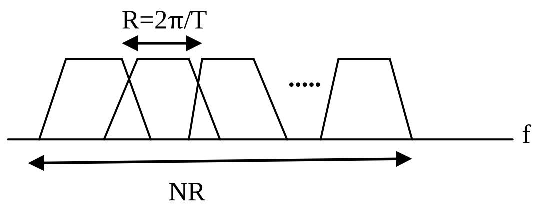
Filtered Multitone (FMT) is another multicarrier communication scheme which has been proposed for DSL applications [8].In FMT, the adjacent subcarriers do not overlap as they are separated by guard bands. Hence, FMT is less bandwidth efficient than the FBMC methods proposed by Chang and Saltzberg.

2.1 Comparison of FMT, OFDM-OQAM and CMT
In OFDM-OQAM, each subcarrier band is double sideband modulated and carries a sequence of QAM symbols. Whereas, in CMT, subcarrier modulation is vestigial sideband which carries a sequence of PAM symbols. Therefore, assuming identical symbol duration and number of subcarriers, the CMT signal occupies half the bandwidth of OFDM-OQAM, hence providing only half of its data rate.

2.1.1 FMT



2.1.2 OFDM-OQAM



2.1.3 CMT

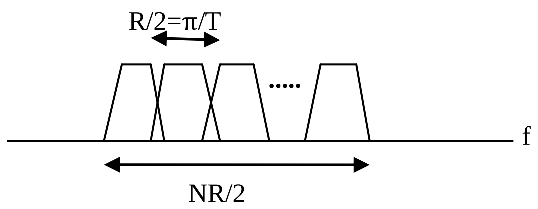
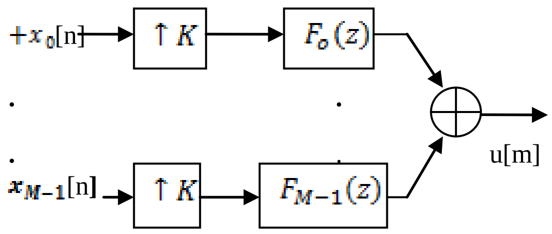


Fig 1: Comparison between CMT, FMT and OFDM-OQAM[9]

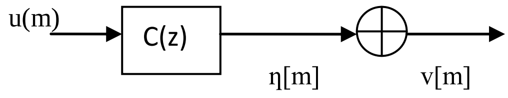
However, FMT introduces guard bands between adjacent subcarriers which are complex modulated. Hence, FMT requires more bandwidth compared to SMT and CMT [9].The relationship between the three techniques is shown in Fig.1.

3. BASICCONCEPT OF A FILTER BANK TRANSCEIVER

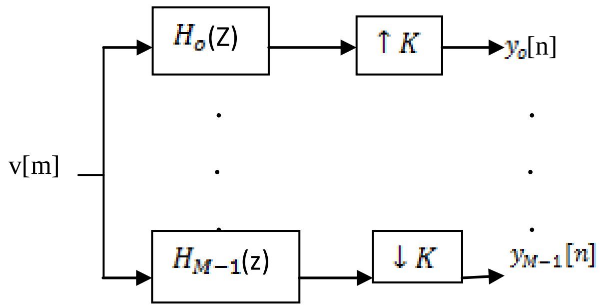
A filter bank transceiver consists of two filter banks, one at the transmitting end (also called synthesis filter) and the other at the receiving end (also called analysis filter). A filter bank contains M digital filters arranged in a parallel configuration. These filters are employed with K-fold digital upsamplers at the transmitter denoted by $\uparrow K$, and with K-fold decimators at the receiver, denoted by $\downarrow K$.To emphasise the multirate nature of the system, two time indices, n and m are used to denote the time samples corresponding to the low sampling rate(symbol rate) and the high sampling rate (channel rate), respectively. There exist many types of filter banks depending on how the filters are designed. In fig.2, the input bit stream is assumed to have already partitioned appropriately and mapped to constellation symbols $x_o(n), \ldots.., x_{M-1}(n)$. In practical implementations, to combat intersymbol interference (ISI) due to the presence of a frequency selective channel, the symbols at the output of the receiving filter bank, $y_o(n) \ldots \ldots, y_{M-1}(n),$ needs to be equalized.



(a)Transmitting filter bank



(b)Channel



(c)Receiving filter bank

Fig 2: A filter bank transceiver[10]

The additional complexity brought by the filter bank in the FBMC receiver can be expressed by taking the FFT of the OFDM receiver as the reference. It depends on the number M of the subchannels in the system and the overlapping factor K. The relationship between M and K is important. Three situations can occur [10].

1) K = M. The transceiver is minimally interpolated,i.e., non-redundant.
2) K > M. The transceiver is over-interpolated,i.e., redundant.
3) K < M. The transceiver is under-interpolated. In this case, some information is irremediably lost. This configuration is not suitable for practical application.

The OFDM transceiver utilizes redundancy to equalize an FIR channel. In FBMC, since the subchannels are well separated, high level narrowband disturbing signals or jammers affect only a few subchannels. Therefore, efficient subchannel equalizer can be used and constraints on synchronisation are relaxed. The subchannel equalizer can be implemented in frequency domain or in the time domain, depending on the receiver filter bank implementation.

4. COMPLEXITY AND COMPATIBILITY OF OFDM-FBMC

4.1 Complexity

FBMC systems are complex when compared to OFDM. The increase in complexity is due to the exchange of the IFFT/FFT by the filter banks. The number of real multiplications per modulation symbol as meausre are used to compare OFDM and FBMC. With OFDM, when applying the Split-Radix algorithm we have,

$$C_{FFT/IFFT} = M(\log(M) - 3) + 4$$

With FBMC, the number of real multiplications per complex symbol can be calculated approximately for the synthesis(SFB) and analysis filter bank(AFB) as follows [11]:

$$C_{SFB} = log_2\left(\frac{M}{2}\right) - 3 + 4K$$

$$C_{AFB} = 2(log_2(M) - 3) + 4K$$

4.2 Compatibility

Since OFDM and FBMC are multicarrier techniques based on the FFT operation, a high degree of compatibility can be obtained if the frequency pattern is the same for both approaches , particularly at initialization. They have a common core, and software defined transmitters and receivers can be efficiently implemented. However, due to the presence of the cyclic prefix in OFDM, the streaming of the signals is different.

4.3 Why FBMC, when OFDM is a proven and widely deployed multicarrier modulation technique?

Esentially,filter banks offfer more degrees of freedom which can be exploited to mitigate certain issues associated with OFDM. For instance, OFDM sufers from poor spectral selectivity since the frequency response of adjacent subchannels overlap significantly with each other.

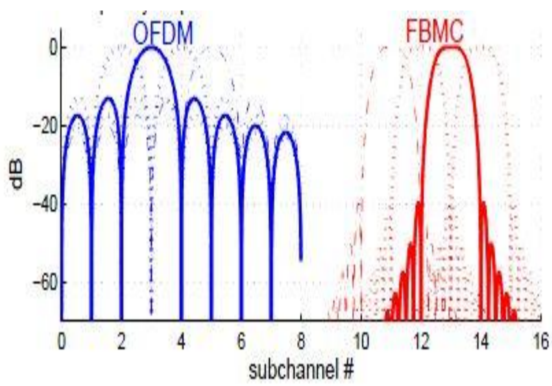


Fig 3: Spectra of OFDM and FBMC subchannels[10]

The poor spectral selectivity may pose problems in the presence of narrowband noise because subchannels adjacent to the narrowband noise will provide a rather poor attenuation which can severely affect the performanc of OFDM. In this case, filter banks can be designed to provide much better spectral selectivity. At a more fundamental level, the problem of selecting the optimal transformation that minimizes the bit error rate for a given transmitted power can be considered using the filter bank framework.

5. FBMC ADVANTAGES AND CHALLENGES

5.1 Advantages

- Efficient usage of the allocated spectrum: FBMC technique, cyclic prefix is not required and also exloits the totality of the symbol period.
- The same filter bank can be used for receiver data signal processing and flexible, high resolution spectrum sensing with high dynamic range.
- High performance spectrum sensing and transmission: Due to the spectral subchannel separation, the functions of spectrum analysis and data transmission can be mixed and performed simultaneously.This serves as a remarkable facility for efficient opportunistic communications.
- Robustness to narrowband jammers and impulse noise.
- Spectral protection of neighbouring users: The out of band attenuation curve of the prototype filter sets the level of spetral protection to the users.

5.2 Challenges

- High computational complexity is associated with FBMC implementation when compared to OFDM. The time domain overlap of subcarrier symbols in filter bank introduces overhead in tightly time multiplexed operation.
- Analog RF performance is critical for implementing generic spectrum sensing with wide bandwidth and high dynamic range.
- The development of MIMO-FBMC system is nontrivial and may be very limited.

6. APPLICATIONS

Cognitive radio communications*:* Compared to OFDM, FBMC offers higher spectral efficiency and is more applicable for the CR network with small size of spectrum holes and also the performance of FBMC is close to that of the perfectly synchronized case because of its frequency localization.

Multiple access networks: In the multiuser context, the uplink of an OFDM network employs a method called multiple access interferenc (MAI) cancellation inorder to meet its basic operational requirements i.,e tight time and carrier synchronization which increases implementational complexity of the system. On the other hand FBMC avoids MAI without any need to perform syschronization.

Access to Television White Space(TVWS): For opportunistic access to the TVWS, flexibilty, low adjacent leakage power ratio (ACLR), frequency agility and sharp spectrum roll off are important factors. In OFDM, implementing filter for avoiding non agile RF filters dramatically increases system complexity. Moreover, OFDM does not have the flexibilty to address TVWS fragmented spectrum while FBMC can met the ACLR co-existence requirements and its peromance is significantly better than OFDM.

Power Line Communication: The intrinsic properties of FBMC makes it well suited for broadband power line communication.In addition to its capability of fully exploitating the time and the channel bandwidth, they also offer high level of protection for the tones and are robust to jammers.Due to the absence of cyclic prefix, the streaming of data is regular in case of FBMC.

MIMO Communications: Multicarrier transmissions particularly OFDM combine easily with MIMO techniques. Whereas in MIMO-FBMC systems, for moderate and highly frequency selective channels, received signals are corrupted by ISI, ICI and IAI(inter antenna interference) and equalization techniques adopted to mitigate the above is not an easy task. Also with imperfect channel state information(CSI), additional significant ICI/ISI terms appear in FBMC and not in OFDM. So far, in adopting the various MIMO techniques, only FMT-based FBMC can offer the same flexibility as OFDM.

7. CONCLUSION

In this paper, a multicarrrier mudulation technique, FBMC evolved from OFDM, the most widely deployed technique for multicarier communication is presented. FBMC outclasses OFDM in terms of spectral effeciency, robustness and spectral protection at a cost of somewhat increased complexity. These superior qualities of FBMC makes it an ideal choice for CR communications, multiple access networks, TVWS and PLC. Whereas FMT is the only FBMC system that can be effeciently extended for transmission over MIMO channels so far .

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