Signal Processing of Filter Bank Multi Carrier for 5G

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Abstract. The spectrum efficiency in fourth-generation (4G) i.e. orthogonal frequency division multiplexing (OFDM) systems has become a major problem at this time due to the increasing need for communication bandwidth. This efficiency is reduced due to the high out-of-band emission (OoBE) that exist. As one of the candidates that still has the potential to be used in the fifth generation (5G) signal modulation method, this paper aims to make observations by out of band emission simulation on a multi carrier filter bank (FBMC). This paper illustrated facets of the 5G with FBMC modulation scheme. To illustrate it, 24 sub-carriers were simulated with each sub-carrier spaced 15 kHz, later the power spectral density of the FBMC signal is plotted. The MATLAB simulation results with the 256-QAM order indicated that FBMC is more advantageous than OFDM because it offers higher spectral efficiency with a difference of 130 dBW / Hz. In other words, this system offers low out of band emission. Previously, an illustration of the FBMC prototype was also shown.

1. Introduction

In signal processing, a filter bank is a series of band-pass filters that dispersed the input signal into components, each carrying one sub-band frequency of the original signal. The decomposition process carried out by the filter bank is called analysis. The measurement product is called a subband signal with as many subbands as there are filters in the filter bank. The method of reconstruction is called synthesis, meaning the complete restoration of the signal arising from the process of filtering. The word filter bank is also widely used in digital signal processing for banks receiving. The differentiation is that the receiver often lowers the substitute to a low center frequency that can be re-sampled at a lower cost. Often the same result can be obtained by underlining the subband bandpass. Several filter bank applications such as graphic equalizer, speech processing, signal compression, image processing, ECG signal compression processing, or for broadband beamforming [1], [2]. One of the modulation approaches for the upcoming 5G mobile networking technologies is the filterbank multicarrier (FBMC). It utilizes multi-carrier techniques that are resistant to fading caused by more than one route of transmission at a time and in addition to being able to work efficiently relative to OFDM, which is used in mobile networking technology of the fourth generation (4G), it is also resistant to intersymbol interference [3].

In fourth-generation (4G) networks, OFDM has been implemented. OFDM is able to combat the latency distribution of wireless networks with an acceptable cyclic prefix (CP) with easy detection methods, which makes it a common solution for current broadband transmission. Traditional OFDM, however, does not satisfy several new specifications needed for 5G networks [4]. In providing solutions to the increasing demands for bandwidth today [5], [6], one of the main things is how to present advanced technology from 4G with spectrum efficiency that is better than 4G. In this case, the conditions for 5G will be low OoBE i.e. less spectral leakage and relief in synchronization.
requirements [7 - 9]. This paper aims to make observations through OoBE simulation on FBMC as one of the candidates [10], [11] which still has the opportunity to be used in the 5G signal modulation process.

1.1. Filter Bank

The filter bank separates the full band signal into multiple subbands and processes them one by one. In detail, the systematic approach uses analytical filters to break down the signal into subbands with smaller bandwidths. As a result, the sampling rate can be lowered (downsampling). After subband processing, to reconstruct the output, the unique sampling rate must be upsampled. Finally, a synthetic filter is used to remove any replica of the signal spectrum that arises due to upsampling. Perfect restoration (PR) is one of the main criteria in the architecture of the filter bank, which intuitively means that the signal is not damaged by the filter bank and the output is a postponed version of the input. Generally, filter banks can be categorized into two main groups: uniform filter banks in which all sampling rates, namely \{n1, n2, nK, ...\}, and non-uniform filter banks where at least one sampling rate is different from the other [12].

![Figure 1. Filter bank structure](image1)

The design of filter banks with incompatible sample sets is complicated by the fact that PR cannot be achieved. A possible goal is to achieve almost PR while the specifications of the analysis and synthesis filters are met. Another approach to achieving nearly PR for non-compatible sampling sets uses a linear double rate system implemented using an LTI filter, conventional sampler, and block sampling. The filter bank is assumed to be maximally decimated [12].

![Figure 2. Example of two channels filter bank](image2)

1.2. FBMC Prototype

FBMC filters every subcarrier modulated signal in a multicarrier system. The prototype filter is a filter that is used for zero frequency carriers and forms the basis of other filters for subcarriers. The filter is defined by an overlapping component, K, which is the sum of overlapping multicarrier symbols in the time domain. The prototype filter sequence can be selected as 2 * K-1 where K = 2, 3, or 4 and selected along with the PHYDYAS project. The current implementation of FBMC uses frequency spread. It uses an IFFT of length L * K with the symbol overlapping the delay L / 2, where L is the subcarriers number. This choice of architecture makes it possible to evaluate FBMC and equate it with other methods of modulation. To achieve full power, offset quadrature amplitude modulation (OQAM) operation is used. The real and imaginary parts of the complex data symbol are not expressed equally since half the length of the symbol is delayed by the imaginary parts. The select of this OQAM is because it has FBMC filters for every subcarrier modulated signal in a multicarrier
system. The prototype filter is a filter that is used for zero frequency carriers and forms the basis of other filters for subcarriers. The filter is defined by an overlapping component, K, which is the number of time domain overlapping multicarrier symbols. The series of prototype filters can be chosen as 2*K - 1 where K = 2, 3, or 4 and selected according to the project PHYDYAS. The current application of FBMC uses frequency spread. It uses an IFFT of length L * K with the symbol overlapping the delay L / 2, where L is the number of subcarriers. This choice of architecture makes it possible to evaluate FBMC and equate it with other methods of modulation. Offset quadrature amplitude modulation (OQAM) operation is used to reach maximum capacity. The real and imaginary parts of the complex data symbol are not expressed equally since half the length of the symbol is delayed by the imaginary parts. The select of this OQAM is because it has much lower out-of-band emission comparing to another type of bank filter [13]. The PHYDYAS filter prototype is used to analyze the interference mitigation in the MIMO system, [9]. Meanwhile, for this 5G study, 64QAM is used for WOFDM simulation [14].

Figure 3. Prototype of FBMC [13]

Figure 4. Pole-zero plot of FBMC prototype

The current implementation of FBMC uses frequency spread. Inter Symbol Interference is a well-known dominant concern in multiparty networks (ISI). Orthogonality is the fundamental theory of ISI reduction involved in OFDM. The complete band available for FBMC is split into subcarriers. Subcarriers do not conform with the orthogonality concept, unlike OFDM. Therefore, ISI becomes a place to solve problems. To work around this problem, FBMC keeps the symbol duration unchanged. Added filtering on the transmitter and receiver side is followed by IFFT / FFT operation to resolve adjacent multicarrier symbols overlapping in the time domain. IFFT length is L * K where the overlapping symbol delay is L / 2, where L represents a number of subcarriers. The synthesis analysis of the filter bank structure is formed by filtering prototypes together with the IFFT / FFT operation. Here a significant ISI emphasis is possible with the prototype filter design. In order to guarantee, an additional coefficient of ISI-free operation was introduced in the frequency domain between the FFT coefficients. This additional coefficient number is known as the overlapping factor which is represented by the K filter. Prototype filter impulse response can be expressed as in equation (1) [15].

\[ pf(t) = 1 + 2 \sum_{m=1}^{K-1} H_m \cos(2\pi \frac{mL}{K}) \]  

(1)

Where Hm is the coefficient shown in table 1.
Table 1. Coefficient $H_m$

| $K$ | $H_0$ | $H_1$ | $H_2$ | $H_3$ |
|-----|-------|-------|-------|-------|
| 2   | 1     | $\sqrt{2}/2$ | -     | -     |
| 3   | 1     | 0.911438 | 0.411438 | -     |
| 4   | 1     | 0.971960 | $\sqrt{2}/2$ | 0.235147 |

$K$ indicates the number of overlapping multicarrier symbols in the time domain.

In [15] above, the FBMC simulation is carried out until the FFT point value is 1024 (SNR 12 dB) by looking at the BER parameter results and comparing them to OFDM. Meanwhile [16] do it for QPSK modulation. Some of the challenges of FBMC investigation proposed by [17] are orthogonality, packet transmission, waveform, and transceiver adaptation issue.

2. Methodology

This research was conducted with MATLAB simulations on the power spectral density parameters. The two OFDM and FBMC systems are compared. Likewise, observing the bit error rate parameter to the signal to noise ratio for both systems. The simulation parameters that we do have the values as shown in Table 2. The subcarrier space takes one of the data from the LTE scalable bandwidth from 20MHz, 15MHz, 10MHz, and less than 5MHz [18] as well as the numerological options in [19]. For simulation repetitions, the Monte Carlo method is used.

Table 2. Simulation parameters

| Parameters                            | Value                        |
|---------------------------------------|------------------------------|
| Number of FFT points, $N$             | 2048                         |
| Guard bands length                    | 212                          |
| The overlapping factor for FBMC, $K$  | 4                            |
| Bit per sub-carrier                   | 8 (for 256 QAM)              |
| Signal to Noise Ratio                 | 15 dB                        |
| Number of subcarriers, $L$            | 24                           |
| Number of OFDM symbols in time, $K_{OFDM}$ | 10                      |
| Number of FBMC time-symbols, $K_{FBMC}$ | 105                       |
| QAM modulation order                  | 256                          |
| Sampling rate                         | $15e3*14*14$ Hz              |
| Shift frequency                       | 50                           |
| Time-frequency spacing                | 1.09                         |
| Simulation repetitions                | 100                          |
| Channel carrier frequency             | $2.5e9$ Hz                   |
| Sub-carrier spacing                   | $15e3$ Hz                    |
| OFDM Cyclic Prefix length             | $1/(14*Sub-carrier spacing)$ |

3. Results and Discussion

With 24 subcarriers for 256 QAM modulation, the power spectral density is shown in figure 5. As the sidelobe magnitude is pressed on FBMC far below OFDM, it causes the out of band emission (OoBE) to be smaller in FBMC against OFDM.
Although the bit error rate (BER) graph has not seen the difference between FBMC and OFDM on the SNR taken in the simulation, which is 15 dB, from the picture it can be seen that the difference in PSD generated by FBMC against OFDM is around 130 dBW / Hz. This is also related to the smaller ripple sidelobe when $K$ is 4, as illustrated in figure 3.
4. Conclusion

Simulation has been carried out. FBMC is a way to resolve the shortcomings of OFDM due to decreased spectral performance and strict criteria for synchronization. This gain makes it considered for 5G networks as one of the modulation techniques.

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