Filter Bank Multicarrier Modulation Schemes for Future 5g Communications

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Abstract*: Future wireless systems will be characterized by a large range of possible uses cases. This requires a stretchy facility of the available time-frequency resources, which is difficult in straight Orthogonal Frequency Division Multiplexing (OFDM). Thus, alternate of OFDM, such as windowing or filtering, try out to be necessary. As an alternative, we can graft a different modulation scheme, such as Filter Bank Multi Carrier (FBMC). Forthcoming mobile systems will be highly diverse and regarded as by an enormous range of possible use cases including large data handling cases extending from enhanced Mobile Broad Band over enhanced Machine Type Communications to Ultra Reliable Low Latency Communications in vehicular communications.*

Keywords OFDM, FBMC, eMTC, URLLC, MCM

I Introduction

Future wireless systems will be characterized by a large range of possible uses cases. This requires a flexible allocation of the available time-frequency resources, which is difficult in conventional Orthogonal Frequency Division Multiplexing (OFDM). Thus, modifications of OFDM, such as windowing or filtering, become necessary. Alternatively, we can employ a different modulation scheme, such as Filter Bank Multi Carrier (FBMC). Future mobile systems will be highly heterogeneous and characterized by a large range of possible use cases, ranging from enhanced Mobile Broad Band (eMBB) over enhanced Machine Type Communications (eMTC) to Ultra Reliable Low Latency Communications (URLLC) in vehicular communications.

Filter bank multicarrier (FBMC) is an alternative transmission method that resolves the above problems by using high quality filters that avoid both ingress and egress noises. Also, because of the very low out-of-band emission of subcarrier filters, application of FBMC in the uplink of multiuser networks is trivial. It can be deployed without synchronization of mobile user nodes signals. In the application of cognitive radios, the filter bank that is used for multicarrier data transmission can also be used for spectrum sensing. On the other hand, compared to OFDM, FBMC falls short in handing multiple-input multiple-output (MIMO) channels, although a few solutions to adopt FBMC in MIMO channels have been reported in the literature; for example, see. Nevertheless, as our recent research study has shown, in the emerging area of massive MIMO, FBMC is found as powerful as OFDM and in some cases superior to OFDM.

II PROBLEM STATEMENT

Filter bank multicarrier (FBMC) is an alternative transmission method that resolves the above problems by using high quality filters that avoid both ingress and egress noises. Also, because of the very low out-of-band emission of subcarrier filters, application of FBMC in the uplink of multiuser networks is trivial. The problems of channel equalization as well as synchronization and tracking methods in FBMC systems are given a special consideration and a few outstanding research problems are identified.

III Existing Methods

Recent discussions on viable technologies for 5G emphasize on the need for waveforms with better spectral containment per subcarrier than the celebrated orthogonal frequency division multiplexing (OFDM). Filter bank multicarrier (FBMC) is an alternative technology that can serve this need. Subcarrier waveforms are built based on a prototype filter that is designed with this emphasis in mind. This paper presents a broad review of the research work done in the wireless laboratory of the University of Utah in the past 15 years. It also relates this research to the works done by other researchers. The theoretical basis based on which FBMC waveforms are constructed is discussed. Also, various methods of designing effective prototype filters are presented. For completeness, poly phase structures that are used for computationally efficient implementation of FBMC systems are introduced and their complexity is contrasted with that of OFDM. The problems of channel equalization as well as synchronization and tracking methods in FBMC systems are given a special consideration and a few outstanding research problems are identified. Moreover, this paper brings up a number of appealing features of FBMC waveforms that make them an ideal choice in the emerging areas of multiuser and massive MIMO networks [1].

In the context of the on-going evolution of satellite communication systems to their next generation, involving higher data rates and increased flexibility, it is of interest to study in depth the applicability of multiple access (MA) multicarrier modulation (MCM) schemes that have shown promise to meet the requirements of the future terrestrial networks. A comparative study of MA schemes employing offset quadrature amplitude modulation (OQAM)-based filter bank multicarrier (FBMC/OQAM) and classical orthogonal frequency division multiplexing (OFDM) is presented in this paper. The considered air-interface follows the latest Digital Video Broadcasting (DVB) family of standards for the satellite return link. Considering a high-power amplifier (HPA) of a very small aperture terminal (VSAT), the performance of the two MA schemes is evaluated in an asynchronous multi-user satellite environment involving time and frequency synchronization errors. Our results indicate that while FBMC-based MA (FBMA) is more sensitive near saturation and in the presence of timing errors, it is more robust to frequency offset errors not only in terms of the Total Degradation (TD) but also in terms of the Spectral Efficiency (SE), since it only needs minimal guard bands among the different users. This is a preliminary study of the potential gains from the integration of the FBMA technology in the satellite infrastructures and standards. Future work will include results on single-carrier modulation (SCM) FBMA as well [2].

IV PROPOSED METHOD

In multicarrier systems, information is transmitted over pulses which usually overlap in time and frequency. Its big advantage is that these pulses commonly occupy only a small bandwidth, so that frequency selective broadband channels transform into multiple, virtually frequency flat, sub-channels (subcarriers) with negligible interference. This enables the application of simple one-tap equalizers, which correspond to maximum likelihood symbol detection in case of Gaussian noise. Furthermore, in many cases, the channel estimation process is simplified, adaptive modulation and coding techniques become applicable, and MIMO can be straightforwardly employed.

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A. CP-OFDM

CP-OFDM is the most prominent multicarrier scheme and is applied, for example, in Wireless LAN and Long Term Evolution (LTE). CP-OFDM employs rectangular transmit and receive pulses, which greatly reduce the computational complexity. Furthermore, the CP implies that the transmit pulse is slightly longer than the receive pulse, preserving orthogonality in frequency selective channels.

B. FBMC-QAM

There does not exist a unique definition for FBMC-QAM. Sacrifice frequency localization, making the modulation scheme even worse than OFDM in terms of OOB emissions. Others sacrifice orthogonality in order to have a time-frequency spacing of $TF \approx 1$ and time-frequency localization.

We, on the other hand, consider for FBMC-QAM a time frequency spacing of $TF = 2$, thus sacrificing spectral efficiency to fulfill all other desired properties. Such high time-frequency spacing increases the overall robustness in a doubly-selective channel, see Section IV. However, the main motivation for choosing $TF = 2$ is the straightforward application in FBMC-OQAM, described in the next subsection.

C. FBMC-OQAM

FBMC-OQAM is related to FBMC-QAM but has the same symbol density as OFDM without CP. To satisfy the Balian-Low theorem, the complex orthogonality condition h$gl1$, $k1(t)$, $gl2$, $k2(t)$i = $\delta(l2-l1)$, $(k2-k1)$ is replaced by the less strict real orthogonality condition $\Re\{$h$gl1,k1(t),gl2,k2(t)$i$\}$ = $\delta(l2-l1),(k2-k1)$. FBMC-OQAM works, in principle, as follows:

1) Design a prototype filter with $p(t) = p(-t)$ which is orthogonal for a time spacing of $T = T0$ and a frequency spacing of $F = 2/T0$, leading to $TF = 2$, see (10), (14).

2) Reduce the (orthogonal) time-frequency spacing by a factor of two each, that is, $T = T0/2$ and $F = 1/T0$.

3) The induced interference is shifted to the purely imaginary domain by the phase shift $\theta_{l,k} = \frac{\pi}{2}(l+k)$ in (2).

Although the time-frequency spacing (density) is equal to $TF = 0.5$, we have to keep in mind that only real-valued information symbols can be transmitted in such a way, leading to an equivalent time-frequency spacing of $TF = 1$ for complex symbols. Very often, the real-part of a complex symbol is mapped to the first time-slot and the imaginary-part to the second time-slot, thus the name offset-QAM. However, such self-limitation is not necessary. The main disadvantage of FBMC-OQAM is the loss of complex orthogonality. This implies particularities for some MIMO techniques, such as space-time block codes or maximum likelihood symbol detection, as well as for the channel estimation.

D. Coded FBMC-OQAM: Enabling All MIMO Methods

In order to straightforwardly employ all MIMO methods and channel estimation techniques known in OFDM, we have to restore complex orthogonality in FBMC-OQAM. This can be achieved by spreading symbols in time or frequency. Although such spreading is similar to Code Division Multiple Access (CDMA), employed in 3G, coded FBMC-OQAM is different in the sense that no rake receiver and no root-raised-cosine filter is necessary. Instead, we employ simple one-tap equalizers which is possible as long as the channel is approximately flat in time (if we spread in

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time) or in frequency (if we spread in frequency). Because wireless channels are highly under spread, such assumption is true in many scenarios. Furthermore, the good time-frequency localization of FBMC allows the efficient separation of different blocks by only one guard symbol and no additional filtering is necessary. Another advantage can be found in the up-link. Conventional FBMC-OQAM requires phase synchronous transmissions $(\theta_{l,k} = \frac{\pi}{2}(l+k))$ which is problematic in the up-link (but not in the down-link) [33]. In coded FBMC, this is no longer an issue because we restore complex orthogonality. The main disadvantage, on the other hand, is the increased sensitivity to doubly-selective channels. This, however, was not an issue in our measurements.

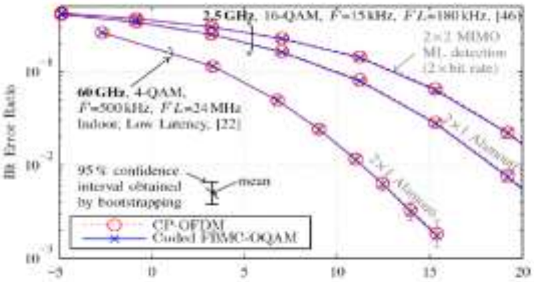

Figure1 Real-world test bed measurements

IFFT Implementation

Practical systems must be much more efficient than the simple matrix multiplication in. It was shown in, for example, that FBMC-OQAM can be efficiently implemented by an Inverse Fast Fourier Transform (IFFT) together with a polyphase network. However, the authors of do not provide an intuitive explanation of their implementation. We therefore investigate an alternative, intuitive, interpretation for such efficient FBMC-OQAM implementation. A similar interpretation was suggested, for example, for pulse shaping multicarrier systems, for FBMC-OQAM (without theoretical justification). However, most papers still when it comes to an efficient FBMC-OQAM implementation. We therefore feel the need to show that the modulation and demodulation step in FBMC is very simple and actually the same as in windowed OFDM.

Figure 2 illustrates such low-complexity implementation and compares FBMC-OQAM to windowed OFDM. Both modulation schemes apply the same basic steps, that is, IFFT, repeating and element-wise multiplications. However, windowed OFDM has overall a lower complexity because the element wise multiplication is limited to a window of size 2*TW* and time-symbols are further apart, that is, *T* = *TW* + *TCP* + *T*0 in windowed OFDM versus *T* = *T*0/2 in FBMC-OQAM. Thus, FBMC needs to apply the IFFT more than two times (exactly two times if *TW* = *TCP* = 0). Of course, the overhead *TW* + *TCP* in windowed OFDM reduces the throughput. Because the signal generation for both modulation formats is very similar, FBMC-OQAM can utilize the same hardware components as windowed OFDM.

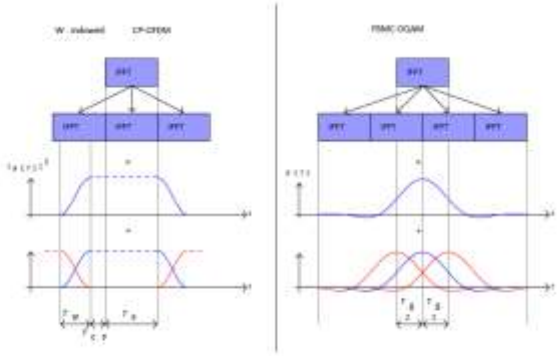
Fig. 4. From a conceptional point of view, the signal generation in windowed OFDM and FBMC-OQAM requires the same basic operations, namely, an IFFT, copying the IFFT output, element wise multiplication with the prototype filter and finally overlapping.

In FBMC-QAM and coded FBMC-OQAM, we can straightforwardly employ all OFDM channel estimation methods known in literature. In FBMC-OQAM, however, this is not possible. The main idea of FBMC-OQAM is to equalize the phase followed by

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taking the real part in order to get rid of the imaginary interference. This, however, only works once the phase is known, thus only after channel estimation. The channel estimation has to be performed in the complex domain where we observe imaginary interference, so that the estimation process becomes more challenging. Possible solutions for preamble-based channel estimation are discussed. However, in a time-variant channel, pilot symbol aided channel estimation is usually preferred over preamble based methods because pilots allow to track the channel. A simple method for pilot aided channel estimation was proposed in, where one data symbol per pilot is sacrificed to cancel the imaginary interference at pilot position. The big disadvantage is the high power of the auxiliary symbols, worsening the PAPR and wasting signal power. Subsequently, different methods have been proposed to mitigate these harmful effects. From all those techniques, we think that the data spreading approach is the most promising method because no energy is wasted, there is no noise enhancement, and the performance is close to OFDM. The idea of is to spread data symbols over several time-frequency positions (close to the pilot symbol) in such a way, that the imaginary interference at the pilot position is canceled. The drawback is a slightly higher computational complexity due to de-spreading at the receiver. This complexity, however, can be reduced by a Fast-Walsh Hadamard transform and by exploiting the limited symbol alphabet (at least at the transmitter).

V PERFORMANCE METRIC

In order to compare different modulation schemes, we have to find a meaningful metric. Some authors, such as, use the BER over E_b/N_0 to compare FBMC with CP-OFDM.

However, in our opinion, E_b/N_0 has some serious drawbacks. To understand why, let us assume a signal 1, consisting of two OFDM symbols (without CP), and a signal 2, consisting of one OFDM symbol where the CP is as long as the useful symbol duration. Thus, both signals occupy the same time duration. However, the same E_b/N_0 implies that there is a 3dB difference in transmit power between the signals. In our opinion, a meaningful comparison must include the same transmit power. This results in the same receive SNR and thus the same BER (AWGN channel). However, signal 1 has twice the data rate. The idea in E_b/N_0 is to account for such different data rates, but a simple power normalization is not a good solution because the symbol power affects the rate only logarithmically. Instead, we should use the achievable rate (capacity) and the throughput.

OFDM based schemes such as WOLA, UFMC and f-OFDM have a relatively high spectral efficiency once the number of subcarriers is high. However, not all possible use cases envisioned for future wireless systems will employ such a high number of subcarriers. For a small number of subcarriers, FBMC becomes much more efficient than OFDM, in particular if the transmission band is shared between different use cases. Many challenges associated with FBMC, such as channel estimation and MIMO, can be efficiently dealt with, as validated by our real-world testbed measurements. Additionally, one-tap equalizers are in many practical cases sufficient once we match the subcarrier spacing (pulse shape) to the channel statistics. In highly doubly selective channels, we can switch from an FBMC-OQAM transmission to an FBMC-QAM transmission, thus deliberately sacrificing spectral efficiency but gaining robustness. This leads to an even higher SIR than in CP-OFDM.

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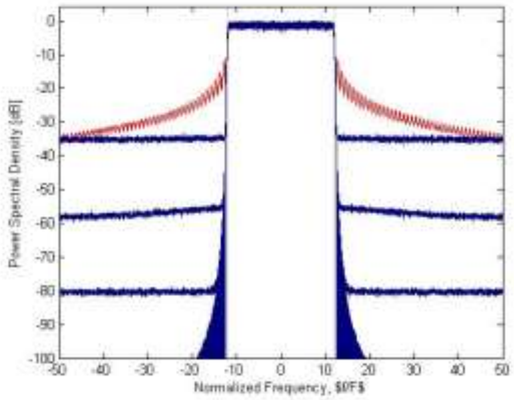
While it is true that the computational complexity of FBMC is higher than in windowed OFDM, both methods require the same basic operations, allowing us to reuse many hardware components.

VI RESULTS ANALYSIS

The length of the cyclic prefix times the sampling rate must be an integer! Therefore, the cyclic prefix length is set to 4.7526e-06s



1. Bit resolution: 4
   Clipping: 8dB
   Realization 100 of 100.
   Time left: 0minutes
   Number of clipped samples:
   OFDM vs FBMC
   534 2167

2. Bit resolution: 8
   Clipping: 9dB
   Realization 100 of 100.
   Time left: 0minutes
   Number of clipped samples:
   OFDM vs FBMC
   22 188
3. Bit resolution: 12
   Clipping: 11dB
   Realization 100 of 100.
   Time left: 0minutes
   Number of clipped samples:
   OFDM vs FBMC
   0 0
4. Bit resolution: 16
   Clipping: 12dB
   Realization 100 of 100.
   Time left: 0minutes
   Number of clipped samples:
   OFDM vs FBMC
   0 0
5. **SNR**: The signal-to-noise ratio, the standard measure of analog noise attribute, is used to assess the quality of the final demodulation signals in an OFDM an FBMC
   SNR [dB] for OFDM:
   7.0525, 79.2731, 102.4364
   SNR [dB] for FBMC:
   33.6739, 55.2173, 65.3076, 65.5105

Advantages:

1. One of the main advantages of OFDM, the low complexity, will be lost.
2. Application of FBMC technique to massive MIMO communications is introduced and its advantages in this emerging technology are revealed.

3. FBMA is increased as the coding rate is increased

Applications:

The Professional Mobile Radio evolution, along with general cognitive radio development are important applications for these techniques.

VII CONCLUSION

In this project, the performance comparison between the most popular multicarrier modulation technique OFDM and a lesser known technique FBMC is performed in terms of Throughput, SNR, BER, packet delivery ratio and dropped packets. 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.

The present 4G Communication Technology based on OFDM is prone to spectrum leakage, strict Orthogonality conditions among entire sub-carriers. Its rectangular pulse shape increases susceptibility to synchronization errors. In order to mitigate the major drawbacks, new Communication technology based on FBMC techniques are suggested for future SDR. It has more spectrum efficiency, more flexibility to use different pulse shape and efficient power control. This FBMC Systems can also be susceptible to Synchronization Errors, Time Offset and Frequency Offset. Though ICI (Interference of Symbols from other subcarriers in the same index) and ISI (Interference of Symbols in different time index from all subcarriers) depends upon Pulse-shape, Channel and Data, it can be mitigated through Channel Equalization, Channel Estimation and Synchronization techniques in the future.

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