Comparison of Filter-Bank Based Multicarrier Systems with Fractionally Spaced Equalisation

By Amr A. Nagy and Stephan Weiss

Dept. of Electronic & Electrical Engineering, University of Strathclyde, Glasgow, Scotland

Abstract

This paper compares two different filter bank multicarrier (FBMC) modulations: a critically sampled and therefore spectrall maximally efficient FBMC orthogonal quadrature amplitude modulation (OQAM) approach, as well as an oversampled (OS)-FBMC system. Under a dispersive channel, FBMC/OQAM and OS-FBMC require equalisation and timing synchronisation, which here is accomplished by a fractionally spaced equaliser updated by a concurrent constant modulus and decision-directed algorithm. Simulation demonstrate that FBMC/OQAM is more difficult to equalise particularly at lower SNR, since its additional CCI terms amplify the equalisation algorithm's gradient noise.

1. Introduction

For 5th generation wireless communications systems, a switch from orthogonal frequency division multiplexing to more general filter bank based multicarrier (FBMC) methods is consider, due to better resilience to synchronisation errors as discussed in e.g. Farhang-Boroujeny 2011. This advantage of FBMC systems is gained through redundancies in terms of guard bands. Subchannels however are not free of intersymbol interference, therefore requiring equalisation when transmitting over dispersive channels, see e.g. Tonello & Pecile 2008.

Amongst FBMC methods, the critically sampled FBMC/ orthogonal quadrature amplidute modulation (OQAM) system by Siohan *et al.* 2002 has gained attention because of its high spectral efficiency, for which e.g. Caus & Perez-Neira 2014, Mestre & Gregoratto 2014 have applied precoding and equalisation at the subband level. In contrast oversampled (OS) FBMC systems in e.g. Tonello & Pecile 2008 offer a lower spectral efficiency, but enable better synchronisation and a lower achievable minimum mean square error of a subsequent equaliser, see e.g. Weiss *et al.* 2010. The purpose of this paper is to compare the OS-FMBC case in Weiss *et al.* 2010 to the critically sampled case of an FBMC/OQAM system.

In the following, we provide a brief overview over FBMC/OQAM and OS-FBMC systems in Sec. 2. Equalisation using a fractionally spaced equaliser for timing synchronisation and equalisation according to Johnson *et al.* 1998 is discussed in Sec. 3, with updating based on a concurrent constant modulus algorithm (CMA) and decision-direct (DD) approach of De Castro *et al.* 2001, Hadef & Weiss 2005. Simulation results and discussions are contained in Sec. 4, with conclusions drawn in Sec. 5.

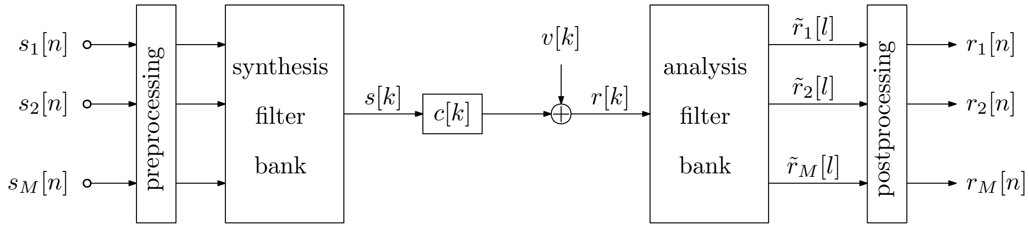

FIGURE 1. Block diagram of a general FBMC system.

2. Filter Bank Multicarrier Structures

The general block diagram of an FBMC system is depicted in Fig. 1. A total of M transmit signals $s_m[n]$, $m = 1 \cdots M$ are multiplexed by a synthesis filter bank, involving upsampling by $K \geq M$. The multiplexed signal $s[k]$ propagates through a dispersive channel with impulse response $c[k]$, and is corrupted by additive white Gaussian noise $v[k]$. In the receiver, the signal $r[k]$ is again demultiplexed by an analysis filter bank into M subchannels $r_m[n]$, $m = 1 \ldots M$, involving decimation by K. The oversampling ration $K/M \geq 1$ controls the redundancy and therefore bandwidth efficiency of the FBMC system. The pre- and postprocessing blocks shown in Fig. 1 will take on specific roles for FBMC/OQAM and OS-FBMC, and their fractionally spaced equalisation.

FBMC/OQAM is a critically sampled system ($K = M$) with maximum spectral efficiency Siohan *et al.* 2002. The spectral overlap of adjacent subchannels is compensated by transmitting OQAM symbols, where the real and imaginary parts are transmitted with a half-symbol period delay. The preprocessing in Fig. 1 thus consists of staggering $\text{Re}\{s_m[n]\}$ and $\text{Im}\{s_m[n]\}$, $m = 1 \ldots M$, such that the synthesis filter bank inputs run at twice the symbol rate. A matching de-staggering operation is contained in a postprocessing block in the receiver, with inputs $\tilde{r}_m[l]$ again running at twice the symbol rate.

Spectral guard bands in FBMC systems with oversampling, $K > M$, permit the use of a modulated filter bank without further preprocessing. In order to later operate a fractionally spaced equaliser, we wish to obtain a twice-oversampled output $\tilde{r}_m[l]$, with the postprocessing a further decimation by two. Efficient implementations of such systems as in Weiss & Stewart 2000 can be extended with some modifications to the case where we need to obtain outputs at twice the symbol rate, see e.g. Mohamad *et al.* 2002.

3. Adaptive Equalisation for FBMC

The length of the channel impulse response $c[k]$ as experienced by the mth subchannel will be generally shortened by the oversampling factor K; however, the channel is likely to include fractional delays w.r.t. the symbol time n, which counteracts this shortening, see Laakso *et al.* 1996. The residual channel impulse response seen by the mth subchannel will lead to inter-symbol interference (ISI), but will also cause a loss of timing synchronisation in the FBMC system, resulting in co-channel interference (CCI). In order to equalise the channel on a per-subband basis and enable robustness towards timing synchronisation errors, in the following we will use a fractionally spaced equaliser as described by Johnson *et al.* 1998 and advocated for FBMC by e.g. Tonello & Pecile 2008, Weiss *et al.* 2010 operating on the signals $\tilde{r}_m[l]$, $m = 1 \ldots M$ in Fig. 1.

For both OS-FBMC and FBMC/OQAM, M fractionally spaced equalisers are applied

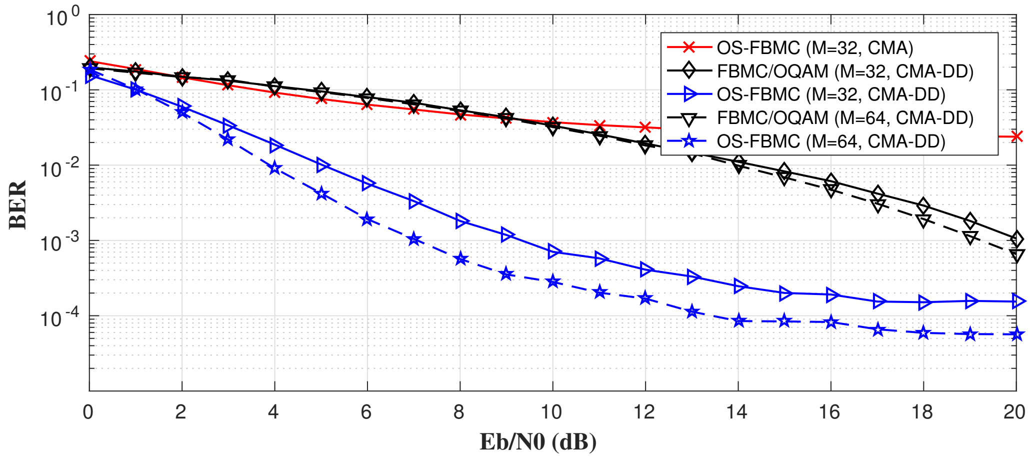

FIGURE 2. BER performances comparison of FBMC/OQAM to OS-FBMC

to $\tilde{r}_m[l]$, $m = 1 \ldots M$. The postprocessing in case of OS-FBMC consists of only a decimation. High selectivity of the filter banks, and a guard band due to $K > M$ means that the equaliser will not be exposed to any CCI. For FBMC/OQAM, only every second real and imaginary part of the equaliser output is de-staggered in the postprocessing stage, with the discarded values corrupted by CCI.

To adapt the fractional delay equaliser, we employ the constant modulus algorithm (CMA) in Johnson *et al.* 1998. For longer channels, this equaliser may converge slowly, and therefore a CMA concurrently operating with a decision-directed (DD) algorithm is utilised, see Hadef & Weiss 2005, De Castro *et al.* 2001. This concurrent method uses CMA update at every step; if the update does not alter the symbol decision, then this decision is deemed correct, and an additional DD update is invoked. Using e.g. a DD-based normalised LMS algorithm (NLMS), its convergence is as fast as an NLMS provided no decision errors are incurred.

4. Simulation Results

The FBMC/OQAM and OS-FBMC systems are compared for $M \in \{32, 64\}$ transmit signals consisting of uncorrelated quaternary phase shift keying sequences. The OS-FBMC system uses upsampling factors of $K \in \{36; 70\}$, i.e. a redundancy of 12.5% and 9.375%, respectively. The channel $c[m]$ is of length 10 with decaying delay profile. CMA and concurrent CMA-DD fractionally spaced equalisers are simulated over different instantiations of channel and transmit signals, with an equaliser length of 10 coefficients and the centre tap initialised to unity, see e.g. Widrow & Walach 1995. The algorithm step size was selected empirically at approx. 10% of its maximally possible value.

Bit error ratio (BER) results are summarised in Fig. 2, averaged over the various simulations once an approximate steady-state performance has been reached. For $M = 32$, updating the fractionally spaced equaliser with the CMA only led to poor adaptation, and hence a very poor BER performance, with only the OS-FBMC system shown in Fig. 2. The concurrent CMA-DD scheme yielded much better adaptation, and the FMBC/OQAM and OS-FBMC systems both converged. Higher multiplexing with $M = 64$ provides slightly enhanced performance for both systems, as in this case the effective channel length is shorter than for $M = 32$, thus easing the burden on the equaliser. Importantly, according to Fig. 2, OS-FBMC gives a systematically better BER performance than FBMC/OQAM, which only starts to catch up for higher SNR values.

Since FBMC/OQAM compared to OS-FMBC suffers not only from ISI but also CCI, and the selected equalisation algorithms belong to the family for stochastic gradients methods, the FBMC/OQAM equaliser experiences a greater level of gradient noise. This in turn can result a larger excess mean squared error for LMS-type stochastic gradient descent algorithms. Therefore, particularly for lower SNR values, the impact of this error term will be dominant compared to the OS-FBMC case, thus underlying the behaviour evident in Fig. 2.

5. Conclusions

In this paper, the critically sampled FBMC/OQAM system has been compared with an oversampled FBMC system when applying per-channel equalisation using a fractionally spaced equaliser. Based on a concurrent CMA and DD updating, this equaliser has been adapted to provide ISI suppression and symbol synchronisation. While the OS-FBMC system is free of CCI, in the FBMC/OQAM approach this leads to a higher excess error at low SNR. Therefore, even though FBMC/OQAM strives for a higher spectral efficiency, it appears to sacrifice some of the robustness that is expected of FBMC systems for 5th generation wireless communications.

REFERENCES

Caus, M., and Perez-Neira, A. 2014 Multi-stream transmission for highly frequency selective channels in MIMO-FBMC/OQAM systems. *IEEE Trans. Signal Processing*, 62(4):786–796.

De Castro, F., de Castro, M., and Arantes, D. 2001 Concurrent blind deconvolution for channel equalization. In *IEEE Int. Conf. Comms*, 2:366–371.

Farhang-Boroujeny,B. 2011 OFDM versus filter bank multicarrier. *IEEE Signal Processing Mag.*, 28(3):92–112.

Hadef, M. and Weiss, S. 2005 Concurrent constant modulus algorithm and decision directed scheme for synchronous DS-CDMA equalisation. In *Proc. IEEE Int. Conf. SSP*, Bordeaux, France, pp. 203–208.

Johnson, C.R., Schniter, P., Endres, T.J., Behm, J.D., Brown, D.R., and Casas, R.A. 1998 Blind Equalization Using the Constant Modulus Criterion: A Review. *Proc. of the IEEE*, 86(10):1927–1950.

Laakso, T.I., Välimäki,V., Karjalainen,M., and Laine, U.K. 1996 Splitting the Unit Delay. *IEEE Signal Processing Mag.*, 13(1):30–60.

Mestre, X., and Gregoratti, D. 2014 A parallel processing approach to filterbank multicarrier MIMO transmission under strong frequency selectivity. In *IEEE ICASSP*, 8078–8082, May 2014.

Mohamad, H., Weiss, S., Rupp, M., and Hanzo, L. 2002 Fast adaptation of fractionally spaced equalisers. *IEE Elec. Lett.*, 38(2):96–98.

Siohan, P., Siclet,C., and Lacaille, N. 2002 Analysis and design of OFDM/OQAM systems based on filterbank theory. *IEEE Transactions on Signal Processing*, 50(5):1170–1183.

Tonello, A.M. and Pecile, F. 2008 Analytical results about the robustness of FMT modulation with several prototype pulses in time-frequency selective fading channels. *IEEE Trans. Wireless Comms*, 7:1634–1645.

Weiss, S. and Stewart, R.W. 2000 Fast Implementation of Oversampled Modulated Filter Banks. *Electronics Letters*, 36(17):1502–1503.

Weiss, S., Millar, A.P., Stewart, R.W., and Macleod, M.D. 2010 Performance of transmultiplexers based on oversampled filter banks under variable oversampling ratios. In *EUSIPCO*, Aalborg, Denmark, pp. 2181–2185.

Widrow, B., and Walach, E. 1995 *Adaptive Inverse Control.* Prentice Hall, Englewood Cliffs, New York.