FBMC and GFDM Interference Cancellation Schemes for Flexible Digital Radio PHY Design

Rohit Datta and Gerhard Fettweis
Vodafone Chair of Mobile Communication,
Technische Universität Dresden,
Dresden, Germany
{rohit.datta, fettweis}@ifn.et.tu-dresden.de

Zsolt Kollár and Péter Horváth
Department of Broadband Infocommunications
and Electromagnetic Theory
Budapest University of Technology and Economics
Budapest, Hungary
{kollar, hp}@mht.bme.hu

***Abstract*—With the opening up of white spaces, efficient use of the fragmented spectrum - TV white space in particular - has become an extremely important focus of research. Apart from efficient spectrum usage, special care needs to be taken to maintain low out-of-band radiation to avoid harmful interference to incumbent services like TV signals and wireless microphones. For this reason, a flexible digital radio with multicarrier modulation scheme is the only solution. In this paper, we show the performance of two innovative multicarrier systems, Filter Bank Multi Carrier (FBMC) and Generalized Frequency Division Multiplexing (GFDM). A simple interference cancellation technique called serial inter-carrier interference cancellation scheme has been used to improve performance of the GFDM system. Channel equalization techniques have been implemented for FBMC.**

Keywords- cognitive radio, white space, PHY design, intercarrier interference, multicarrier modulation

I. INTRODUCTION

Opportunistic use of the white spaces (WS) in the licensed spectrum has now been allowed by regulatory bodies like the Federal Commission for Communication (FCC) [1] [2], and hence it is now one of the most researched topics in the field of Cognitive Radio (CR) [3] and wireless communications. A multicarrier flexible digital PHY architecture with suitably low out-of-band radiation is designed towards this same goal.

We aim at designing a robust PHY adapted to a heavily fragmented spectrum, with a vision that the transmitted waveform should achieve high spectrum efficiency while meeting the constraints of a flexible RF architecture. Digital implementation of such a flexible radio is a top priority, so that we can reduce implementation complexities of an analog RF frontend.

Orthogonal Frequency Division Multiplexing (OFDM) is typically the first choice for any multicarrier system, but it suffers from significant spectral leakage to neighboring frequency bands, in this case, the incumbent TV channels. Previous efforts have been in the direction of sidelobe suppression with cancellation carrier insertion [4]. With strict specifications, where incumbent signals are not to be interfered with, innovative multicarrier modulation techniques with different pulse shaping filters are proposed as alternate solutions for CR Physical Layer (PHY) design in white spaces.

To improve spectrum efficiency, two modulation techniques are considered in this paper: Filter Bank Multi Carrier (FBMC) [5] and Generalized Frequency Division Multiplexing (GFDM) [6]. They aim at achieving low adjacent leakage spectrum, thereby inducing higher spectral efficiency. These techniques appear to be good candidates for CR PHY. Additional requirements and performance parameters are analyzed in the first part of the paper. The added flexibility in these FBMC or GFDM approaches is the ability to choose different pulse shapes for the opportunistic signal, which reduces the side lobe leakage into the incumbent frequency band.

A simple inter carrier cancellation measure called Serial Inter-Carrier interference cancellation (SIC) [7] scheme has been implemented for GFDM and its performance is shown to have improved over previous results [6]. For the improvement of the FBMC system performance, channel equalization has been implemented.

The remainder of the paper is organized as follows: Sections II and III consider the system design of the FBMC system followed by the multipath channel equalization techniques for it. Sections IV and V detail the GFDM system model and the serial interference cancellation scheme respectively; followed by the conclusion.

II. FBMC SYSTEM MODEL

FBMC systems are based on the orthogonal lapped transform [8] and filter bank theory [9]. The basic structure of one possible implementation of an FBMC system is depicted in Fig. 1. Similar to OFDM, the information bits are first mapped to symbols X drawn from the complex QAM constellation alphabet. The real parts are modulated by a cosine filter bank where only sub-bands with even indexes are used and the imaginary parts are modulated by a sine filter bank using odd indexes. To achieve near perfect reconstruction, an offset of half the symbol overlapping duration is applied at the output of the sine filter bank – similar to the offset quadrature amplitude modulation technique. The basic frequency domain construction of the filter banks can be also seen in Fig. 1. Each constellation symbol is spread over the sub-band and is filtered by a prototype filter which fulfills the Nyquist criterion. In FMBC, these filter bank structures are implemented in a computationally efficient manner using an N-IFFT combined with a polyphase network [8]. The filter bank generates time domain symbols with a length of M times – M being the overlapping factor – the N-point OFDM symbol. In order not to lose data rate, these symbols will overlap by a factor M. Due to the Nyquist criterion, the symbols can be separated at the receiver and a perfect reconstruction is possible. For example, if $M = 4$ then 4 FBMC symbols will overlap each other. The resulting transmitted signal, s_n is the sum of the overlapping FBMC symbols generated by the filter bank.

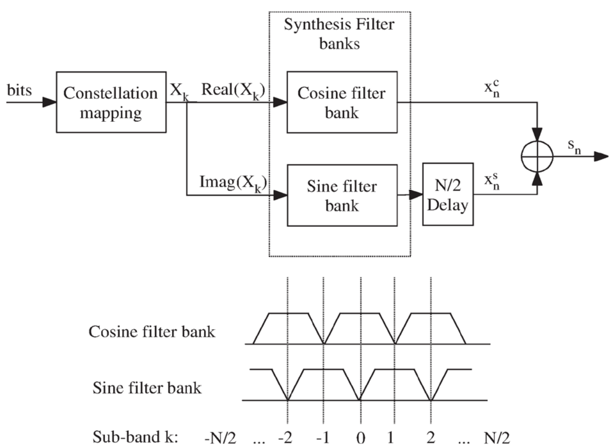

Figure 1. Block diagram of an implementation of the FBMC transmitter with spectral layout of the cosine and sine filters.

III. FBMC EQUALIZATION

A. Per subcarrier channel equalization

The channel equalization for FBMC can be performed similar to OFDM with a Cyclic Prefix (CP) in the frequency domain. In an approach presented in [10] [11], per-subcarrier MMSE equalization is applied. These channel equalization coefficients for each subcarrier have to be modified slightly according to [9], due to inter symbol interference introduced by the multipath channel and the missing cyclic prefix.

B. Iterative decision feedback equalization

In this section, we introduce an iterative decision feedback scheme where the most reliable decision values are fed back after a decision to minimize the residual ISI in the received signal [12] has been taken. This decision feedback scheme is shown in Fig. 2. The basic idea is to regenerate the transmitted signal, but only in those sub-bands which are reliable, and filter these sub-bands with a known channel filter. The idea can be summarized as the following: if we strive to make a decision for the i^{th} FBMC symbol of the cosine filter bank, then we reconstruct as much as possible from the surrounding symbols i-3, i-2…i+3 which overlap with it (both sine and cosine) based on a certain selection criteria. Then, during the decision phase, on the i^{th} FBMC symbol the ISI of the known neighboring symbols can be subtracted, thereby reducing the noise stemming from ISI and leading to better performance. The selection criterion is defined based on the constellation diagram. We assume a certain confidence interval around each constellation point. The complex modulation symbols which fall within this interval are considered as reliable. During the iteration process, the interval can be enlarged as the ISI is minimized. This approach is motivated by the observation that an error floor limits performance of FBMC in the high SNR region.

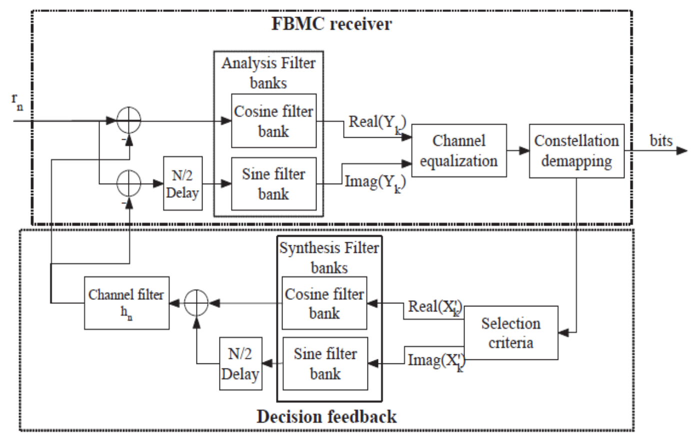

Figure 2. FBMC receiver with decision feedback loop

C. Simulation results

In this section, we present simulation results for the channel equalization scheme previously discussed for OFDM and FBMC systems. The simulation parameters used are summarized in Tab. I. In Fig. 3, bit error ratios are presented for three scenarios: transmission channel with no multipath and with two different multipath delays. In the Additive White Gaussian (AWGN) channel with no multipath, FBMC has a better performance compared to OFDM because it does not apply any CP, leading to a higher data rate. In the first multipath channel, the channel delay spread is relatively small, a quarter of the size of the CP. In the second multipath scenario, a delay spread with the same length as the cyclic prefix was applied. The amplitudes of the channel taps are Rayleigh distributed in both cases. It can be seen that for small delay spreads, the FBMC system exhibits an advantage in terms of BER when compared to OFDM due to the additional CP which reduces the data rate. On the other hand, as a channel with a longer delay spread is introduced, the FBMC system reaches an error floor due to a larger ISI and is outperformed by the OFDM system. The results for the iterative technique can be visualized in Fig. 4. It can be seen that the error floor is much smaller, a considerable amount of ISI is removed and the performance after the fourth iteration is close to that of the OFDM system. In practical systems, with the use of forward error coding (FEC), this phenomenon can be mitigated or at least bounded under a meaningful bit error rate.

TABLE I. Simulation parameters

Parameter	OFDM	FBMC
CP – Cyclic prefix	16	-
N – FFT/IFFT length	64	64
M – Overlapping factor	1	4
Modulation	16-QAM	16-QAM
Modulated subcarriers/subbands	48	48
L - Channel length	CP/4 & CP	CP/4 & CP

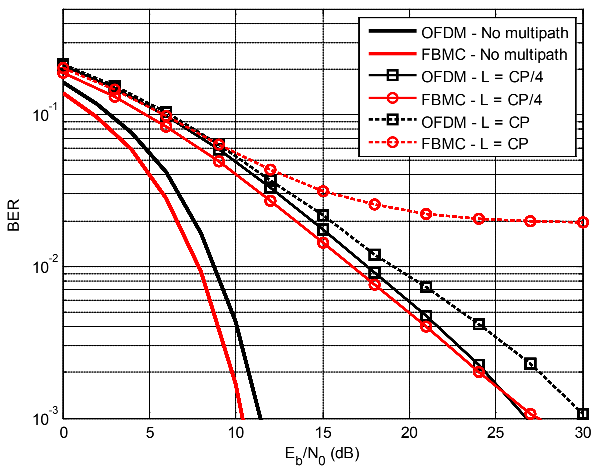

Figure 3. BER performance of FBMC and OFDM various channel scenarios.

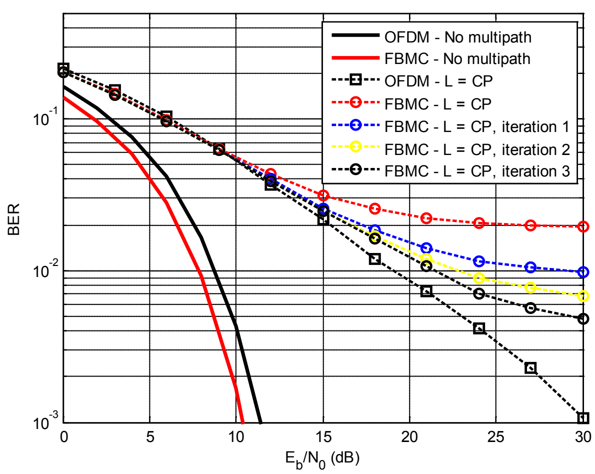

Figure 4. BER performance of OFDM and FBMC with Iterative decision feedback equalization.

IV. GFDM System Model

GFDM is an innovative multicarrier modulation technique which is suitable for cognitive PHY in fragmented white spaces. Unlike OFDM, where we have rectangular pulse shaping; in GFDM, we have an added flexibility of choosing a suitable pulse, like a Root Raised Cosine (RRC) or Raised Cosine (RC). This pulse shaping technique brings the advantage of extremely low out-of-band radiation of the opportunistic signal into the incumbent legacy band, as RRC pulses have lower side lobes when compared to rectangular pulses in OFDM.

As described in [5], GFDM is a multicarrier system incorporating a tail-biting technique. By applying Tx/Rx filters via circular convolution, the length of the transmitted signal is kept independent of the length of the pulse shaping filters [13].

In the transmitter part of the system, as shown in Fig. 5, the binary data is QPSK/QAM modulated and then the transmit pulse shaping filter shapes the modulated data. Then, after sub carrier up-conversion the transmitter transmits the modulated signals with a cyclic prefix.

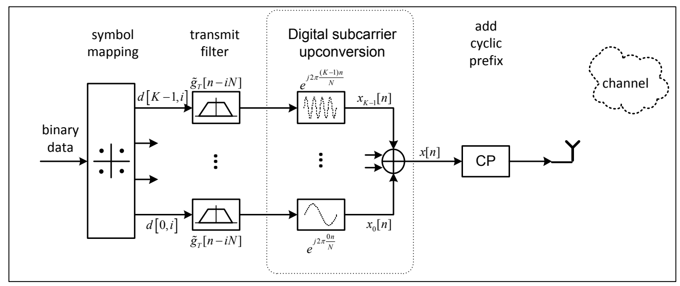

Figure 5. GFDM transmit system model.

In the receiver part of the system, as shown in Fig. 6, the CP is removed and then sub carrier down-conversion is performed after equalization. The received signal is then passed through the matched received pulse shaping filter, followed by a sampler and a detector to get back binary data.

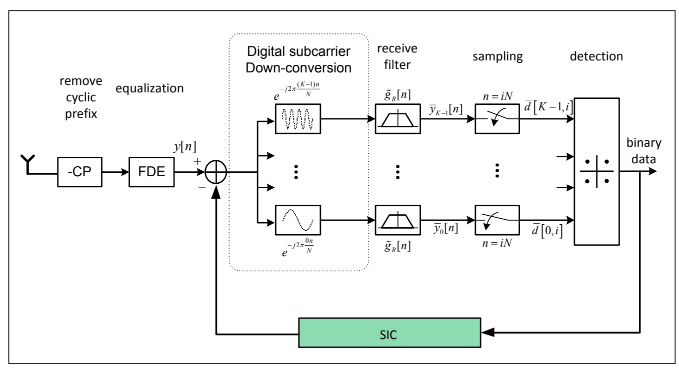

Figure 6. GFDM receive system model.

The receiver also shows the serial interference cancellation scheme that has been implemented to improve performance of the GFDM system.

As shown in [6], since we have fewer numbers of subcarriers when compared to OFDM, the PAPR of this system is better than that of OFDM by about 1 dB at 1% CCDF. Different pulses, like RRC, introduce non-orthogonality and cause ICI between the subcarriers, and as shown in Fig. 8, the BER curve of GFDM is degraded compared to the theoretical AWGN BER curve. As shown in the next section, GFDM can achieve good performance with simple equalization schemes, while requiring a reasonable complexity increase in the equalizer.

V. GFDM-ICI Cancellation Scheme

A simple inter carrier interference cancellation scheme, Serial Interference Cancellation (SIC) can improve the performance of the GFDM system. In our simulation setup, we have considered the AWGN channel and an RRC pulse. The interference under consideration is the self inter carrier interference that crops up because of the pulse shaping filters. The significant contributions to the interference are from the adjacent subcarriers. One simple way to cancel out the effect of this interference is to perform Serial Interference Cancellation (SIC) [7].

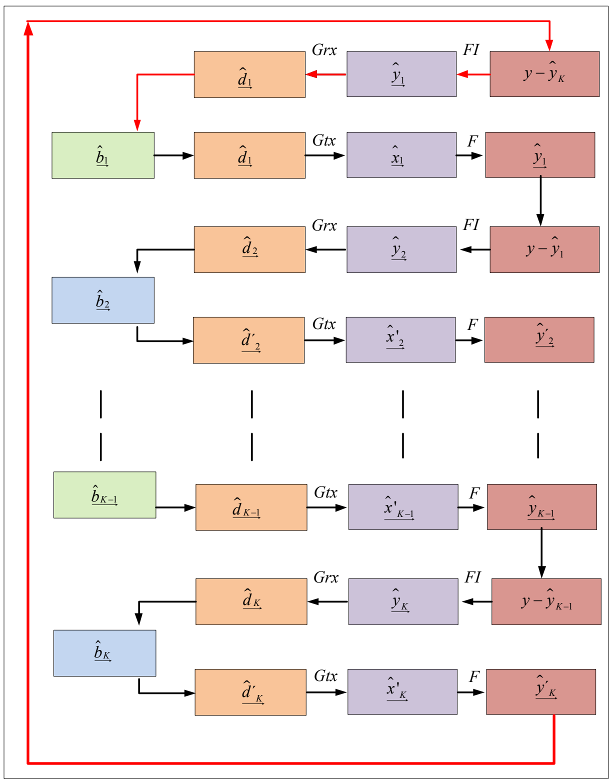

Figure 7. SIC Block Diagram

Once a particular subcarrier is detected, it is modulated once again and pulse shaping is done before it is up-converted to the subcarriers, to generate the approximate transmitted signal, as shown in Fig. 7. Then, this estimate of the transmitted signal is subtracted from the received signal to cleanse the effect of a given subcarrier on its adjacent one.

The entire receiver processing is done thereafter, viz. subcarrier down-conversion, receive filtered, and then sampled. Then, the next subcarrier is detected and as usual, the above mentioned methodology is applied to cleanse the effect of adjacent subcarriers on the carrier of interest.

The GFDM BER performance improvement is shown in Fig. 8. for QPSK and in Fig. 9. for a 16 QAM constellation. Thus we see, SIC improves the BER perform-

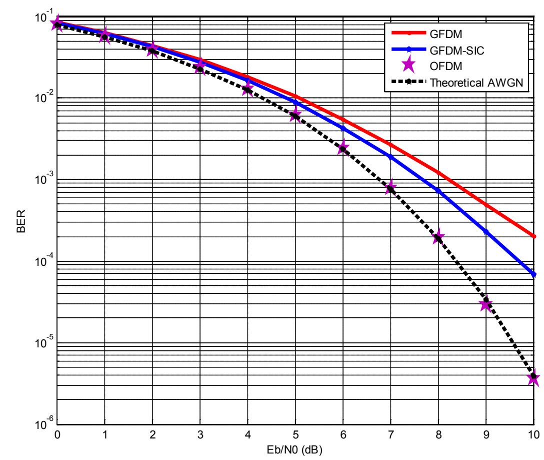

Figure 8. QPSK GFDM-SIC BER performance vs. theoretical AWGN

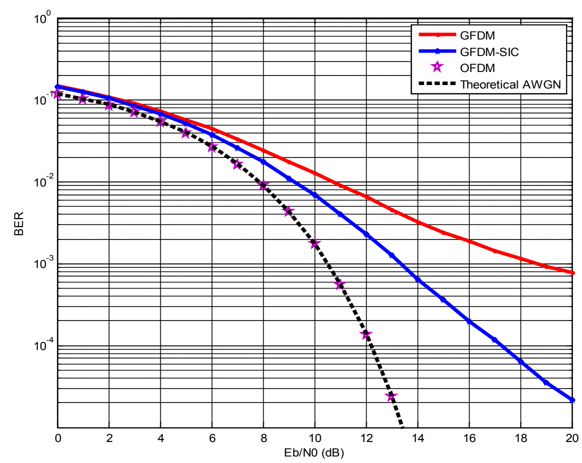

Figure 9. 16QAM GFDM-SIC BER performance

-ance when compared to the results in [6]. The GFDM BER performance can be improved further by implementing a parallel interference cancellation scheme.

VI. Conclusion

For digital implementation of a flexible radio operating in a fragmented spectrum, designing a digital, flexible PHY is of utmost importance. The FBMC concepts together with equalization techniques undertaken to improve the FBMC performance are shown. Per subcarrier equalization and iterative feedback equalizer have been implemented for FBMC. The simulations show improved BER performance; these results are compared to conventional CP-OFDM.

Here, we have also shown how a system based on multi carrier OFDM with the added flexibility of choosing the pulse shaping filters improves the out of band leakage of opportunistic signals to the incumbent bands. At the same time, going for simple equalization schemes like SIC improves the BER performance of the GFDM system. Overall, this paper presents two of the most innovative PHY design schemes for a flexible digital radio with equalization schemes implemented with better BER performance. The PHY designs discussed here are going to be digitally implemented within the scope of an FP7 EU project called QoSMOS.

ACKNOWLEDGMENT

The research leading to these results was derived from the European Community's Seventh Framework Program (FP7) under Grant Agreement number 248454 (QoSMOS).

REFERENCES

[1] ETSI EN 300 744 V1.6.1 (2009-01). Digital Video Broadcasting (DVB), Framing Structure, Channel Coding and Modulation for Digital Terrestrial Television. European Standard ETSI, 2009.

[2] IEEE, "Supplement to IEEE Standard for Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHZ Band," IEEE Std 802.11a-1999.

[3] J. Mitola, "Cognitive radio: an integrated agent architecture for software defined radio", Ph.D. thesis, Royal Institute of Technology, Stockholm, Sweden, May 2000.

[4] S. Brandes, I. Cosovic and M. Schnell, "Sidelobe suppression in OFDM systems by insertion of cancellation carriers", VTC2005-Fall, pp.152–156, Sept. 2005.

[5] P. Siohan, C. Siclet and N. Lacaille, "Analysis and design of OFDM/OQAM systems based on filterbank theory", IEEE Transactions on Signal Processing, vol.50, no.5, pp.1170-1183, May 2002.

[6] G. Fettweis, M. Krondorf and S. Bittner, "GFDM – General Frequency Division Multiplexing", in Proceedings of IEEE 69th Vehicular Technology Conference (VTC Spring'09), 26-29 April 2009.

[7] A. Clark, ''Adaptive Detection with Intersymbol-Interference Cancellation for Distorted Digital Signals'', in proceedings of the IEEE Transactions on Communications, Vol 20, Issue 3, Part 2, Pg 350 – 361, 1972.

[8] H. S. Malvar, "Extended lapped transforms: Properties, applications, and fast algorithms," IEEE Trans. on signal processing, vol. 40, no. 11, pp. 2703–2714, Nov. 1992.

[9] P. P. Vaidyanathan, Multirate systems and filter banks. Prentice-Hall Inc., 1993

[10] A. Ikhlef and J. Louveaux, "An enhanced MMSE per subchannel equalizer for highly frequency selective channels for FBMC/OQAM systems", in Proceedings of IEEE Signal Processing Advances in Wireless Communications (SPAWC'09), June 2009.

[11] T. Ihalainen, T. H. Stitz, and M. Renfors, "Efficient per-carrier channel equalizer for filter bank based multicarrier systems", in Proceedings of IEEE International Symposium on Circuits and Systems (ISCAS '05), May 2005, pp. 3175–3178.

[12] Zs. Kollár, G. Péceli and P. Horváth, "Iterative decision feedback equalization for FBMC systems", in Proceedings of IEEE First International Conference on Advances in Cognitive Radio, (COCORA 2011), April 2011.

[13] N. Michailow, M. Lentmaier, P. Rost and G. Fettweis, "Integration of a GFDM Secondary System in an OFDM Primary System", FuNeMs 2011, Warsaw, Poland.

[14] H. Zhang, D. Le Ruyet and M. Terre, "Spectral Efficiency Analysis in OFDM and OFDM/OQAM Based Cognitive Radio Networks", in Proceedings of IEEE 69th Vehicular Technology Conference (VTC Spring'09), 26-29 April 2009.

[15] R. Datta and et. all, ''Flexible Multicarrier PHY Design for Cognitive Radio in White Space'', accepted for publication in 6th International ICST Conference on Cognitive Radio Oriented Wireless Networks (CrownCom'11), 01-03 June 2011.