Reduced Complexity Transceiver Processing for MIMO FBMC Systems

Madushanka Soysa, *Student Member, IEEE,* Nandana Rajatheva, *Senior Member, IEEE,* and Matti Latva-aho, *Senior Member, IEEE*

***Abstract*—Filter bank multicarrier (FBMC) scheme is currently under investigation as a viable candidate for radio access replacing the current orthogonal frequency division multiplexing (OFDM). This is due to the possibility of higher spectral efficiency and less susceptibility to synchronization errors through flexible pulse shape design as opposed to traditional rectangular shape or $sinc$ waveform, in this case accompanied without the cyclic prefix. As a consequence, FBMC systems have a significant amount of inter-carrier-interference (ICI) and inter-symbol-interference (ISI), which degrades the system performance when operating under fading channels, though by design these affects are negligible in AWGN channels. In this paper we analyze the bit error rate (BER) performance of a multiple input multiple output (MIMO) FBMC system comprehensively and show that the system can achieve low error performance. The performance is evaluated for various linear and non-linear transceiver processing techniques, which attempt to mitigate the effect of ICI and ISI in MIMO FBMC systems. In particular we propose punctured Tomlinson Harashima precoding (THP) technique which shows feasibility of FBMC with significantly lower BER.**

***Index Terms* - Filter bank; OQAM; receiver processing; precoding**

I. INTRODUCTION

Multicarrier modulation (MCM) methods are practically preferable due to their robustness against frequency selectivity and ability to employ adaptive modulation and coding in different subcarriers, as opposed to traditional single carrier schemes where receiver processing is quite complicated. Among these, orthogonal frequency division multiplexing (OFDM) is the most widely used technique in various applications as of today [1]. One of the disadvantages of OFDM is because of the guard interval or the cyclic prefix that is used to eliminate the inter-symbol interference (ISI) which results in a reduction of the spectral efficiency [2]. In addition, as a result of the rectangular pulse shape that is used in OFDM, its susceptibility to synchronization errors increases. Filter bank multicarrier (FBMC) was analyzed in [3] to essentially overcome these issues. A number of authors proposed and investigated FBMC several decades ago and these include [4]–[6]. The OFDM receiver is relatively straightforward, however, as the demand for higher data rates or faster signaling increases, there is incentive now, to look for alternatives considering also the inherently unsynchronized nature of the uplink and recent thrust in the applications of cognitive schemes where synchronization is a challenge.

The main difference in OQAM compared to standard QAM is transmitting symbols as real and imaginary samples and the offset of half of the symbol period between them [7]. The technique is to use two types of orthogonal filter banks known as $sine$ and $cosine$ which are generated from a prototype filter investigated in [8]. In FBMC, the complex data symbol is mapped to real symbols, and the orthogonality between carriers and symbols is then required only in the real axis. The pulse shape of this prototype filter is different from the rectangular window used in OFDM and more localized in both frequency and time domain, hence the out of band frequency leakage is minimized. This provides flexibility to use a different pulse shape than the rectangular pulse in OFDM, which is better localized in both frequency and time domains [9]. One such prototype filter known as PHYDYAS filter [10] was presented in [11]. In [12], filter designs based on isotropic orthogonal transform algorithm (IOTA) and time-frequency localization (TFL) were investigated. The sensitivity to time asynchronism of PHYDYAS and IOTA filters was studied in [13].

A drawback in FBMC systems is the error floor caused by inter-carrier-interference (ICI) and inter-symbol-interference (ISI) in fading channels is though in AWGN channels these effects are minimal by design. Therefore, receiver processing techniques and precoding techniques to mitigate the effect of ICI and ISI in FBMC systems need to be designed. An interference mitigating technique based on the Alamouti coding scheme and maximum likelihood detection (MLD) is presented in [14]. There, they have taken the advantage of combining FBMC with MIMO technique and its diversity gain to improve the performance of the system. On the other hand, [15] has introduced an efficient scheme based on spatial diversity to cancel the ISI and ICI in OFDM/OQAM. Also here they have shown how the multiuser gain can be used to enhance the system performance compared to the OFDM Alamouti scheme.

In [16], a two-step algorithm, equalization with interference cancelation (EIC) was proposed, and evaluated for prototype filters derived through the optimization with respect to the TFL criterion and derived from IOTA prototype function a single antenna FBMC system. The performance of EIC with minimum mean square error (MMSE) equalization in MIMO FBMC systems was analyzed in [17]. Precoding techniques based on the signal-to-leakage-power-and-noise-ratio (SLNR) for MIMO FBMC systems were presented in [18]

Madushanka Soysa is with the Department of Electrical and Computer Engineering, University of California at San Diego, La Jolla, CA 92093-0407 USA (e-mail: msoysa@ucsd.edu).

Nandana Rajatheva and Matti Latva-aho are with the Department of Communication Engineering, University of Oulu, Finland (e-mail: rrajathe@ee.oulu.fi, matti.latva-aho@ee.oulu.fi)

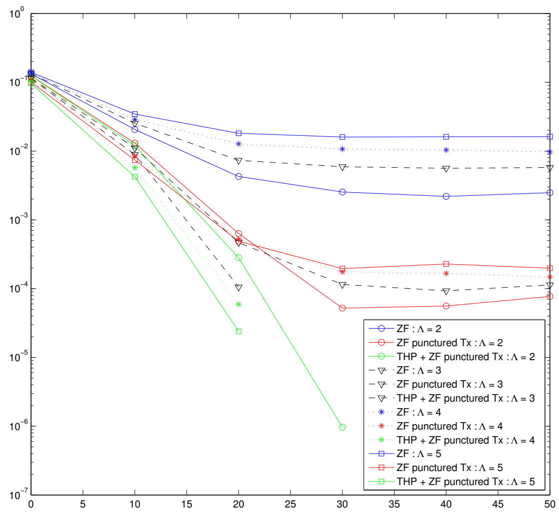

Fig. 1: Average BER parametrized by the number of channel taps Λ. ($2M = 16$, $L = 63$, $N_A = 2$, $\sum_{l=1}^{\Lambda-1} \mathbb{E}\left[|h_{p,q}[l]|^2\right] = 0.2$, $r_{\max} = 3$, $\epsilon = 1$)

and [19]. These, however, have certain limitations in terms of assumptions made and the channels considered. The results on MIMO systems are somewhat limited [9], and interference environment is simplified.

We investigate the performance of linear receiver processing and precoding techniques in MIMO FBMC systems. We further evaluate the performance of the EIC method proposed in [16], for MIMO FBMC systems. We investigate the performance of an iterative EIC technique, and the performance of EIC in conjunction with error correction coding and lower the error floor significantly. The performance of these precoding and receiver processing techniques were evaluated using the average bit error rate (BER) as the performance metric through simulations. The results presented are quite comprehensive, show new directions for further investigations and help considerably bridge the gap in realistic interference conditions.

II. System model

We consider a multicarrier MIMO-FBMC system with $2M$ subcarriers, with a single transmitter and a receiver, each equipped with N_A antennas. The filter used is $g[k]$ and the filter length is L. We consider a time-invariant Rayleigh fading channel, where the channel delay spread spans Λ sampling intervals. We assume that all antenna paths undergo independent fading. For the receiver processing techniques discussed, we assume the receiver has perfect channel state information (CSI). For the precoding methods discussed, we assume perfect CSI is available at both the transmitter and the receiver.

We look at the performance of the punctured THP processing with different number of channel taps (Λ) in Fig. 1. Here, while varying Λ, we keep $\sum_{l=0}^{\Lambda-1} \mathbb{E}\left[|h_{p,q}[l]|^2\right] = 1.2$, $\mathbb{E}\left[|h_{p,q}[0]|^2\right] = 1$ and $\mathbb{E}\left[|h_{p,q}[l]|^2\right] = \frac{0.2}{\Lambda-1}$, for $l \in [1, \Lambda-1]$. While the performance of zero forcing (ZF) worsens as Λ increases, the average BER under THP processing does not increase with Λ. The average BER for THP processing appears to be lower for higher Λ in the low SNR region (i.e. $\frac{E_s}{N_0} \leq 20$).

References

[1] B. Le Floch, M. Alard, and C. Berrou, “Coded orthogonal frequency division multiplex [tv broadcasting],” *Proceedings of the IEEE*, vol. 83, no. 6, pp. 982 – 996, 1995.

[2] N. Zorba, S. Pfletschinger, and F. Bader, “Increasing the performance of ofdm-oqam communication systems through smart antennas processing,” in *First International ICST Conference, MOBILIGHT 2009, Athens, Greece*, May 2009.

[3] 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, 2002.

[4] B. Hirosaki, “An orthogonally multiplexed qam system using the discrete fourier transform,” *IEEE Trans. Commun.*, vol. 29, pp. 982–989, 1981.

[5] R. W. Chang, “Synthesis of band-limited orthogonal signals for multichannel data transmission,” *Bell Syst. Tech. J.*, vol. 45, pp. 1775–1796, 1966.

[6] B. R. Saltzberg, “Performance of an efficient parallel data transmission system,” *IEEE Trans. Commun. Technol.*, vol. 15, pp. 805–811, 1967.

[7] H. Bölcskei, “Orthogonal frequency division multiplexing based on offset qam,chapter in advances in gabor analysis.”

[8] M. Bellanger, “Physical layer for future broadband radio systems,” in *IEEE Radio and Wireless Symposium (RWS)*, 2010, pp. 436–439.

[9] B. Farhang-Boroujeny, “Ofdm versus filter bank multicarrier,” *IEEE Signal Processing Magazine*, vol. 28, no. 3, pp. 92–112, 2011.

[10] “Physical layer for dynamic spectrum access and cognitive radio (phydyas),” *7th Framework Programme project http://www.ict-phydyas.org/*, 2010.

[11] M. Bellanger, “Specification and design of a prototype filter for filter bank based multicarrier transmission,” in *IEEE International Conference on Acoustics, Speech, and Signal Processing, 2001. Proceedings. (ICASSP ’01). 2001*, vol. 4, 2001, pp. 2417–2420 vol.4.

[12] P. Siohan and C. Roche, “Cosine-modulated filterbanks based on extended gaussian functions,” *IEEE Transactions on Signal Processing*, vol. 48, no. 11, pp. 3052–3061, 2000.

[13] Y. Medjahdi, D. Le Ruyet, D. Roviras, H. Shaiek, and R. Zakaria, “On the impact of the prototype filter on fbmc sensitivity to time asynchronism,” in *2012 International Symposium on Wireless Communication Systems (ISWCS)*, 2012, pp. 939–943.

[14] R. Zakaria and D. Le Ruyet, “A novel filter-bank multicarrier scheme to mitigate the intrinsic interference: Application to mimo systems,” *IEEE Transactions on Wireless Communications*, vol. 11, no. 3, pp. 1112–1123, 2012.

[15] N. Zorba and F. Bader, “Spatial diversity scheme to efficiently cancel isi and ici in ofdm-oqam systems,” *Journal of Computer Systems, Networks, and Communications*, vol. 2010, 2010.

[16] H. Lin, C. Lele, and P. Siohan, “Equalization with interference cancellation for hermitian symmetric ofdm/oqam systems,” in *IEEE International Symposium on Power Line Communications and Its Applications, 2008. ISPLC 2008.*, 2008, pp. 363–368.

[17] A. Ikhlef and J. Louveaux, “Per subchannel equalization for MIMO FBMC/OQAM systems,” in *IEEE Pacific Rim Conference on Communications, Computers and Signal Processing, 2009. PacRim 2009.*, 2009, pp. 559–564.

[18] U. Jayasinghe, N. Rajatheva, and M. Latva-aho, “Application of a leakage based precoding scheme to mitigate intrinsic interference in fbmc,” in *IEEE International Conference on Communication*, June 2013.

[19] ——, “Leakage based multi user beamforming scheme to mitigate interference in mimo-fbmc,” in *WSA 2013 - 17th International ITG Workshop on Smart Antennas*, March 2013.

[20] H. Lin and P. Siohan, “A new transceiver system for the ofdm/oqam modulation with cyclic prefix,” in *IEEE 19th International Symposium on Personal, Indoor and Mobile Radio Communications, 2008*, 2008.

[21] C. Windpassinger, R. F. H. Fischer, T. Vencel, and J. Huber, “Precoding in multiantenna and multiuser communications,” *IEEE Transactions on Wireless Communications*, vol. 3, no. 4, pp. 1305–1316, 2004.