A novel FBMC/OQAM scheme facilitating MIMO FDMA without the need for guard bands

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***Abstract*—In Filterbank Multicarrier with Offset QAM (FBMC/OQAM) systems, real-field orthogonality is usually not sufficient to isolate two resource blocks in the frequency domain assigned to different users applying distinct MIMO pre-coding for spatial multiplexing or beamforming. In this paper, we propose a novel scheme to avoid inter-block interference by adopting single band (SSB) filtering on the edge subcarriers of each block. Such filtering is able to maintain the real-field orthogonality condition for the subcarriers within a block while attaining the complex-field orthogonality at the block edges. To support the proposed bi-uniform filterbank structure, a novel resource mapping scheme is devised.Through simulation results it is shown that the proposed scheme can efficiently support pre-coded MIMO transmission in FBMC, achieving the same BLER performance as in OFDM.**

Keywords*—*FBMC/OQAM, Complex Field Orthogonality, Pre-coded MIMO

I. Introduction

Filterbank Multicarrier with Offset QAM (FBMC/OQAM) [1], [2] is currently one of the waveform candidates for the 5G mobile system, owing to its excellent waveform localization and high spectral efficiency [3], [4]. Most favourable property of the waveform localization is its potential to substantially relax the synchronization requirement, thus enabling massive machine connections forthe Internet of Things with a simplified uplink access. Some recent works [5], [6] have revealed that FBMC transceiver is highly robust against time-synchronization misalignment and can correct carrier frequency offset (CFO) with very low complexity.

OQAM signaling relaxes the orthogonality to the real-field only, which requires some redesign of signal processing algorithms designed for orthogonal frequency-division multiplexing (OFDM) systems. This holds in particular for multiple-input multiple-output (MIMO) algorithms, which have therefore been in the focus of recent FBMC research. For point-to-point transmission using linear minimum mean square error (MMSE) receivers, it has been shown in [7], [8] that FBMC-MIMO can achieve the same link performance as OFDM systems. However, in frequency division multiple access (FDMA) systems, where multiple users are allocated to different frequency resource blocks, the real-field orthogonality is not sufficient for a proper isolation of the resource blocks assigned to different users. As a consequence, strong inter-block-interference (IBI) may occur if blocks are individually pre-coded based on the users' channel state (as in the downlink) or if the resource blocks of different users have experienced individual channel distortion (as in the uplink). To allow for the desired isolation in FBMC, state-of-the-art solutions suggest to insert one empty subcarrier between the resource blocks, such as proposed by the EU FP7 PHYDYAS project [7], [9]. For a synchronous system, this solution results in a clear loss of spectral efficiency, which has been considered a severe drawback in multi-user transmission for FBMC-MIMO.

In this paper, a novel scheme for FBMC transmission is proposed, where the edge subcarriers between the transmission blocks are filtered with a single side band (SSB) prototype filter to establish the complex field orthogonality, thus avoiding the need for any guard carriers. The proposed scheme relaxes the original uniform filterbank structure of FBMC to a bi-uniform one, enabling to increase the flexibility of resource usage in the system at the cost of a marginal complexity increase.

II. System Model

For FBMC/OQAM modulation, each subcarrier $c \in \{1, ..., M\}$), with M being the number of subcarriers, is modulated according to

$$s_c[m] = \sum_{n=-\infty}^{+\infty} d_{c,n} p[m - n\frac{M}{2}] e^{j\frac{2\pi c}{M}(M-\frac{D}{2})} e^{\phi_{c,n}} \quad (1)$$

where $d_{c,n}$ is a real-valued PAM symbol, $p[m]$ is the prototype filter with filter length $L = KM$, K is the overlapping factor, the causal delay factor is given by $D = (L-1)/2$, and the phase term is $\phi_{c,n} = j^{(\pi/2)(c+n)}$. Signal orthogonality in OQAM is in the real-field only. Assuming an AWGN channel, intrinsic interference caused by adjacent subcarriers in the other complex dimension is simply discarded at the receiver after matched filter operation by applying the real operator $\Re\{.\}$. If the signal is transmitted over a channel with complex coefficients, the channel needs to be equalized by linear operation first to re-establish the real-field orthogonality before the real operator should be applied.

In practice, the prototype filters are usually Nyquist and real valued linear phase finite impulse response (FIR) filters, such as PHYDYAS [9], IOTA [10], root raised cosine (RRC) etc. The PHYDYAS filter is frequently used in the existing literature for OQAM, which has steep roll-off in frequency domain. With this filter, the spectra of subcarrier signals overlap for adjacent subcarriers only, while subcarriers spaced more than one subcarrier apart experience effectively no interference.

III. Proposed Scheme

The idea of the proposed scheme is to establish a complex field orthogonality between adjacent subcarriers located at the

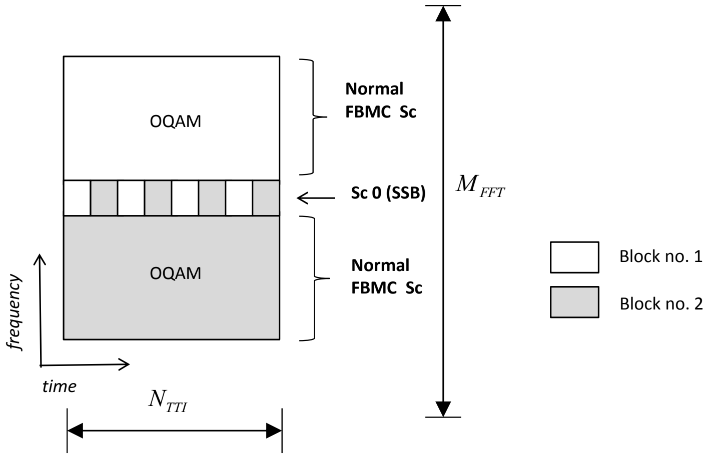

Fig. 1. Proposed resource mapping scheme.

edge of resource blocks, yielding a complete isolation of those blocks in frequency domain.

We assume that $sc0$ is the edge subcarrier between two resource blocks. The complex orthogonality can be established if instead of a linear phase prototype filter $p[m]$ a pair of SSB filters is used, namely the lower side band (LSB) prototype filter $p_l[m]$ and upper side band (USB) $p_u[m]$ on $sc0$. The LSB and USB filters are given by

$$p_l[m] = \frac{\sqrt{2}}{2}(p[m] + j\mathcal{H}_p[m]) \tag{2}$$

$$p_u[m] = \frac{\sqrt{2}}{2}(p[m] - j\mathcal{H}_p[m]) \tag{3}$$

which are derived from the original real-valued prototype filter $p[m]$ and its Hilbert transform $\mathcal{H}_p[m]$.

The derived complex-field orthogonality between LSB and USB allows for a novel resource block division between two adjacent blocks on $sc0$, as depicted in Fig. 1. Specifically, instead of the conventional resource mapping principle where one subcarrier is either allocated to the first or to the second resource block in frequency domain, the novel mapping scheme allocates the SSB filtered odd-th and even-th symbols on $sc0$ to the two transmission blocks in an alternating manner. For the case of pre-coded MIMO transmission, this yields the odd-th and even-th symbols on $sc0$ being applied different beamforming weights.

For ease of illustration, we choose the FS-FBMC implementation [5], where the signals are synthesized and analyzed based on a FFT with KM stages. The filters are realized in the frequency domain by modulating each subcarrier with $2K - 1$ filter coefficients. We assume here the use of PHYDYAS prototype filter $p[m]$, where $K = 4$ and its frequency response being constituted of four distinct filter coefficients $H_i, i \in \{0, \ldots, 3\}$. The edge subcarrier $sc0$ for the odd symbol is modulated by the frequency response of the LSB prototype filter, given by the coefficients

$$\sqrt{2}([H_3, H_2, H_1, H_0/2, 0, 0, 0]) \tag{4}$$

For the even symbol, the frequency response of the USB prototype filter is used, given by the coefficients

$$\sqrt{2}([0, 0, 0, H_0/2, H_1, H_2, H_3]) \tag{5}$$

Fig. 3 illustrates modulation of $sc0$ with this USB filter. All other subcarriers in the resource block are filtered with the conventional prototype $p[m]$, given by the coefficients

$$[H_3, H_2, H_1, H_0, H_1, H_2, H_3] \tag{6}$$

as illustrated in Fig. 3 for subcarrier $sc1$. Transforming the above filter coefficients to time domain yields the frequency-sampled PHYDYAS prototype filter

$$p[m] = H_0 + 2\sum_{k=1}^{K-1} H_k \cos\left(2\pi\frac{km}{KM}\right), \tag{7}$$

whereas the proposed LSB prototype filter based on $p[m]$ yields

$$\tilde{p}_l[m] = \sqrt{2}\left(\frac{H_0}{2} + \sum_{k=1}^{K-1} H_k \left(\cos(2\pi\frac{km}{KM}) + j\sin(2\pi\frac{km}{KM})\right)\right) \tag{8}$$

which contains the Hilbert approximation as

$$\tilde{\mathcal{H}}_p[m] = 2\sum_{k=1}^{K-1} H_k \sin(2\pi\frac{km}{KM}) \tag{9}$$

The approximated LSB prototype filter is illustrated in Fig. 2. The USB prototype filter $\tilde{p}_u[m]$ can be calculated accordingly. By using the proposed prototype filter $\tilde{p}_l[m]$, the Hilbert approximation yields a loss of Nyquist property, which causes an error vector magnitude (EVM) loss of -34 dB for the symbols within the same resource block, while the residual IBI to other blocks amounts to less than -11.4 dB.

IV. Performance Evaluation

In this section, we evaluate the block error rate (BLER) performance of the proposed FBMC/OQAM scheme in LTE-like downlink system with all the basic parameters similar to LTE setting. The evaluated system is supporting multi-user access in downlink with each user being assigned to three resource blocks in total.

For the fair comparison between OFDM and FBMC, we use the same basic setting, antenna set-up, and coding block

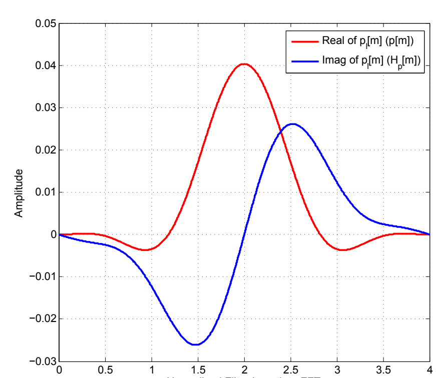

Fig. 2. Approximated LSB $\tilde{p}_l[m]$of PHYDYAS prototype filter.

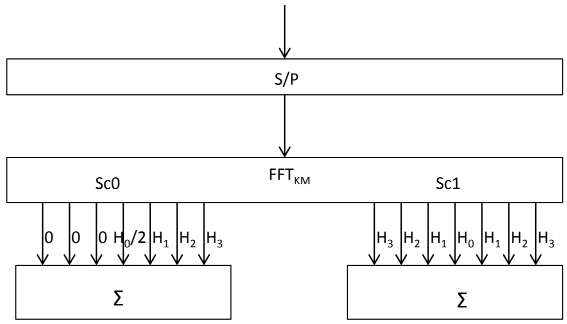

Fig. 3. Proposed FS implementation for synthesis filterbank.

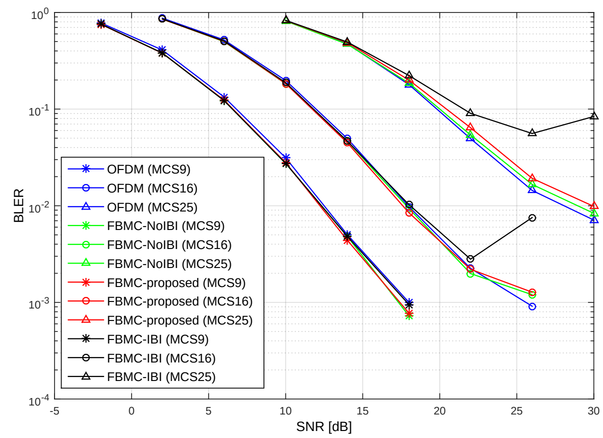

Fig. 4. BLER of 2×1 Beamforming based MISO for SCME Urban Macro channels with a user speed 3km/h.

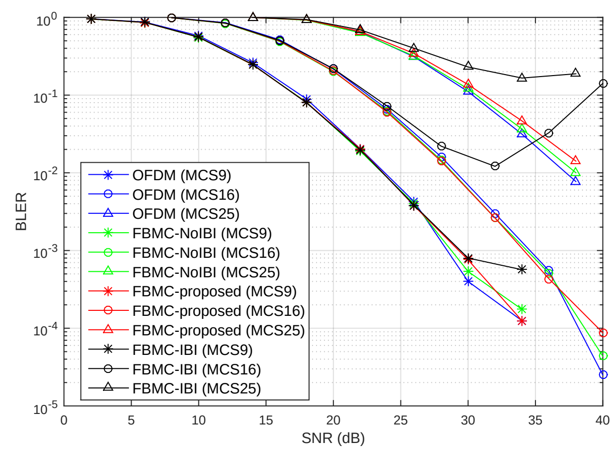

Fig. 5. BLER of 4×4 codebook based precoded MIMO for SCME Urban Micro channels with a user speed 4km/h.

size. It should be noted that, due to the deprivation of cyclic prefix (CP) and using smaller spectral guard band, the FBMC scheme is generally more efficient in frame design, yielding an overall higher spectral efficiency of 12% compared to its LTE-OFDM counterpart.

In Fig. 4, we simulated the downlink beamforming for a multi-user system with 2×1 MIMO configuration, based on full channel state information available at the transmitter. For FBMC, three schemes have been considered:

1) FBMC-NoIBI: conventional FBMC/OQAM scheme with one vacant subcarrier between different blocks
2) FBMC-proposed: the proposed FBMC/OQAM scheme with SSB modulated subcarrier between blocks assigned to different users
3) FBMC-IBI: conventional FBMC/OQAM scheme without any vacant subcarrier between different blocks, resulting in severe IBI

From the simulation results, we observe that the IBI due to different beamforming weights between the users can be avoided completely by using the proposed scheme. For the IBI case, however, there is a performance error floor for FBMC at high SNR. With the novel scheme, each individual FBMC precoding block can now perform the corresponding beamforming transmission with its full degrees of freedom while attaining the same performance as LTE-OFDM.

Fig. 5 shows the BLER performance of LTE compliant codebook based pre-coding for a multi-user system with 4×4 MIMO configuration, applying 4-stream spatial multiplexing per user with MMSE equalizer. We observe here the same performance trend for the codebook based MIMO spatial multiplexing: FBMC applying the novel scheme is achieving the same BLER performance as OFDM while maintaining its favourable waveform property and spectral efficiency advantage.

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