Impact of adjacent-channel interference on transmission performance in asynchronous FBMC/OFDM systems

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Abstract: This paper investigates adjacent-channel interference (ACI) influence on asynchronous systems consisting of filter bank multicarrier (FBMC) and orthogonal frequency-division multiplexing (OFDM), under multipath fading channels. FBMC inhibits out-of-band (OOB) radiation more than OFDM, by subcarrier-wise filtering. This results in ACI reduction, while causing inter-symbol interference (ISI) and inter-carrier interference (ICI) under multipath fading channels. In this paper, we evaluate the bit error rate (BER) performance of asynchronous FBMC/OFDM systems, considering the ACI and multipath fading, using computer simulations.

Keywords: filter bank multicarrier (FBMC), orthogonal frequency-division multiplexing (OFDM), out-of-band (OOB) radiation, adjacent-channel interference (ACI), multipath fading

Classification: Wireless Communication Technologies

References

[1] R.V. Nee and R. Prasad, *OFDM for Wireless Multimedia Communications*, Artech House, 2000.
[2] B. Farhang-Boroujeny, “OFDM versus filter bank multicarrier,” *IEEE Signal Process. Mag.*, vol. 28, no. 3, pp. 92–112, May 2011. DOI: 10.1109/msp.2011.940267
[3] G. Wunder, P. Jung, M. Kasparick, T. Wild, F. Schaich, Y. Chen, S.T. Brink, I. Gaspar, N. Michailow, A. Festag, L. Mendes, N. Cassiau, D. Ktenas, M. Dryranski, S. Pietrzyk, B. Eged, P. Vago, and F. Wiedmann, “5GNOW: Non-orthogonal, asynchronous waveforms for future mobile applications,” *IEEE Commun. Mag.*, vol. 52, no. 2, pp. 97–105, Feb. 2014. DOI: 10.1109/mcom.2014.6736749
[4] C. Sexton, Q. Bodinier, A. Farhang, N. Marchetti, F. Bader, and L.A. DaSilva, “Coexistence of OFDM and FBMC for underlay D2D communication in 5G networks,” Proc. 2016 IEEE Globecom Workshops (GC Wkshps), pp. 1–7, Dec. 2016. DOI: 10.1109/glocomw.2016.7848863
[5] H.A. Mahmoud, T. Yucek, and H. Arslan, “OFDM for cognitive radio: Merits and challenges,” *IEEE Wireless Commun.*, vol. 16, no. 2, pp. 6–15, April 2009. DOI: 10.1109/mwcom.2009.4907554
[6] S. Filin, D. Noguet, J.-B. Dore, B. Mawlawi, O. Holland, M.Z. Shakir, H. Harada, and F. Kojima, “IEEE 1900.7 standard for white space dynamic spec-
1 Introduction

Orthogonal frequency division multiplexing (OFDM) is the most popular multicarrier technique. It is used in several wireless communication applications, including mobile communication, wireless local area networks (WLANs), and digital terrestrial television. OFDM can surpass multipath fading by inserting a guard interval (GI) suitable for broadband wireless communication [1]. However, an inherent drawback of OFDM is the high out-of-band (OOB) radiation due to a rectangular time-domain window [2]. Moreover, OFDM requires wide guard bands, which typically occupy approximately 10% of the available bandwidth, to suppress the impact of interference on adjacent wireless networks. Therefore, OFDM is not always suitable for use in asynchronous dynamic spectrum access scenarios, such as those involving heterogeneous networks [3], device-to-device (D2D) communication [4], cognitive radio [5], and television white spaces [6].

To overcome the above-mentioned drawbacks, filter bank multicarrier (FBMC) has attracted increased attention as a feasible alternative to OFDM. The FBMC operation is based on offset quadrature amplitude modulation (OQAM) and pulse shaping of each subcarrier. This inhibits OOB radiations while maintaining symbol orthogonality [2, 7]. Accordingly, FBMC is considered a promising technique for realizing asynchronous access in the 5G era [3, 4, 6]. However, FBMC is susceptible to inter-symbol and inter-carrier interferences (ISI and ICI, respectively) due to multipath fading [8, 9], which must be considered in broadband wireless communication applications. Therefore, the transmission performance of asynchronous FBMC and OFDM systems must be comprehensively investigated considering the influence of the adjacent-channel interference (ACI) and multipath fading.

In view of the above-described background, we investigate the bit error rate (BER) performance of asynchronous FBMC/OFDM systems under the influence of
the ACI and multipath fading. Although a prior study has evaluated the performance of these systems influenced by multipath fading, the same multicarrier scheme has been assumed between the desired and undesired systems [10]. Moreover, although different multicarrier schemes have been assumed in [11], only specific ACI scenarios where OFDM is interfered by FBMC have been considered. To overcome these limitations of extant studies, we evaluate the performance of asynchronous FBMC/OFDM systems by performing numerical simulations under comprehensive ACI scenarios involving different multicarrier schemes. This validates the influence of system-level differences on the overall transmission performance.

2 Asynchronous system model

In this section, we introduce the operating principle of FBMC prior to the asynchronous system model. Fig. 1(a) shows the FBMC system configuration comprising \( N \) subcarriers. The OQAM pre-processing is performed at the transmitter to maintain orthogonality among the QAM symbols. During the OQAM pre-processing, each QAM symbol is separated into its real and imaginary parts, which are staggered in time by half a symbol period. Subsequently, the OQAM symbols are upsampled by \( N/2 \) and pulse-shaped using synthesis filters. The synthesis filter of the \( k \)-th subcarrier \( g_k[l] \) can be expressed as

\[
g_k[l] = p[l] \exp \left( \frac{2\pi}{N} k \left( l - \frac{L_p - 1}{2} \right) \right) \quad (l = 0, 1, \cdots, L_p - 1),
\]

where \( p[l] \) denotes the impulse response of a prototype filter of length \( L_p = KN + 1 \), with \( K \) denoting the overlapping factor. Assuming the Mirabbasi-Martin prototype filter \((K = 4)\) to be used in this case, \( p[l] \) can be expressed as [7]

\[
p[l] = P_0 + 2 \sum_{i=1}^{K-1} P_i \cos \left( \frac{2\pi li}{KN} \right), \quad \left\{
\begin{array}{ll}
P_0 = 1, & 
P_1 = -0.97195983 \\
P_2 = 0.70710678, & 
P_3 = -0.23514695.
\end{array}\right.
\]

All pulse-shaped signals are combined into a single waveform and transmitted. The transmitted signal \( s[l] \) can be expressed as

\[
s[l] = \sum_{k=0}^{N-1} (g_k[l] * x_k[l])
= \sum_{k=0}^{N-1} \left( \sum_{l'=0}^{L_p-1} g_k[l'] x_k[l-l'] \right).
\]

where * denotes the convolution operation and \( x_k[l] \) is the upsampled OQAM symbol of the \( k \)-th subcarrier.

At the receiver, the received signal \( r[l] \) is decomposed into \( N \) subcarrier signals using the analysis filters \( f_k[l] \) and subsequently downsampled by \( N/2 \). The analysis filters represent the time-reversed and complex-conjugated versions of synthesis filters, and hence, \( f_k[l] = g_k^*[L_p - 1 - l] = g_k[l] \). The orthogonality between the received OQAM symbols after downampling \( y_k[n] \) is retained in additive white noise.
Gaussian noise channels. However, this orthogonality in multipath fading channels, which must be considered in broadband wireless communication, is destroyed owing to the occurrence of ISI and ICI. This results in performance degradation. Therefore, the linear minimum mean-square error (MMSE) equalizer $w_k[n]$ is generally applied to the received OQAM symbols to mitigate the effects of ISI and ICI [8]. Next, the equalized OQAM symbols are subjected to OQAM post-processing, and the original QAM symbols are generated.

Fig. 1(b) shows the difference between the power spectral densities corresponding
to FBMC and OFDM, where $T_{sam}$ is the sampling period, the number of subcarriers $N = 32$, oversampling factor $M = 4$, FBMC overlapping factor $K = 4$, and OFDM GI length $T_G = 32T_{sam}$. From Fig. 1(b), it can be seen that compared to OFDM, OOB radiation is drastically reduced in FBMC system owing to the pulse shaping of each subcarrier. Thus, FBMC can be considered a promising technique for solving the problem of ACI between asynchronous systems. However, as already mentioned, the actual FBMC performance is limited by the effects of ISI and ICI, unlike OFDM. Therefore, it is important to verify the impact of ACI on the transmission performance in asynchronous FBMC/OFDM systems involving multipath fading channels.

Fig. 1(c) shows the asynchronous system model for our performance evaluation. As shown Fig. 1(c), there are two transmitters of desired and undesired systems using FBMC or OFDM. The carrier frequency difference between these systems is set to $\Delta f_c$ normalized by the subcarrier spacing $\Delta f$, and the desired signals interfered by the undesired signals are received through independent multipath fading channels. The time offset between the desired and undesired signals $\Delta t$ changes randomly.

3 Numerical results

The discussion in this section validates the influence of ACI on the BER performance in asynchronous FBMC/OFDM systems involving multipath fading channels. In our performance evaluation, we consider $N = 32$, $M = 4$, and 16QAM is considered as the modulation scheme. Moreover, the 32-ray exponentially decaying Rayleigh fading is assumed as a propagation channel. The GI length given by $T_G = 32T_{sam}$ is observed to eliminate ISI in OFDM. The Mirabbasi-Martin filter [7] with $K = 4$ and 3-tap MMSE linear equalizer [8] are employed in FBMC. The desired-to-undesired signal ratio is set to $0 \; \text{dB}$ during the basic performance evaluation.

Fig. 2 shows the BER performance versus the average carrier-to-noise ratio (CNR), where the delay spread $\tau_{rms} = 2.0T_{sam}$ or $8.0T_{sam}$ and carrier frequency $\Delta f_c = 33\Delta f$ or $48\Delta f$. In Fig. 2, the theoretical BER in flat Rayleigh fading channels is shown for reference. From Fig. 2, it can be observed that the BER performances when interfered by FBMC become better than those when interfered by OFDM, thanks to lower OOB radiation from FBMC. Moreover, in the case of $\tau_{rms} = 2.0T_{sam}$, OFDM exhibits worse BER performance than FBMC, regardless of the adjacent systems. This is because the ACI is enhanced by an OFDM-specific rectangular window. However, in the case of $\tau_{rms} = 8.0T_{sam}$, FBMC exhibits worse BER performance than OFDM due to the FBMC-specific ISI and ICI. Particularly, for $\Delta f_c = 48\Delta f$, OFDM outperforms FBMC, regardless of the adjacent system.

Fig. 3 shows the BER performance versus delay spread with the average CNR $\Gamma$ set to 30 dB. From Fig. 3, it is found that the BER performance of OFDM remains nearly unaffected by the delay spread owing to the elimination of ISI via GI insertion. In contrast, the BER performance of FBMC deteriorates with an increase in the delay spread owing to the occurrence of ISI and ICI. As observed, for $\Delta f_c = 48\Delta f$, the BER performance of FBMC is inferior to that of OFDM corresponding to a relatively large delay spread, such as $\tau_{rms} > 5.0T_{sam}$. This can be attributed to the influence of ISI and ICI becoming dominant over that of ACI.
4 Conclusion

In this paper, we investigated the impact of ACI on the BER performance in asynchronous FBMC/OFDM systems involving multipath fading channels. Numerical results showed that the lower BER is exhibited when interfered by FBMC than by OFDM, owing to the lower OOB radiation from FBMC. Further, FBMC exhibits worse BER than OFDM, especially in cases involving a large multipath delay, due
to the FBMC-specific ISI and ICI.

In future investigations, we intend to compare the transmission performances of asynchronous FBMC/OFDM systems in terms of their spectrum efficiency while considering the impact of transmission efficiency losses induced by the guard band and GI insertion.