International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 7 Issue: 12
***Article Received:** 25 July 2019 **Revised:** 12 September 2019 **Accepted:** 30 November 2019*

Comparative Evaluation of Spectral Efficiency in Multicarrier Modulation Techniques

N.Vaijayanthi,

[1]Professor, Department of Electronics and Communication Engineering, Indra Ganesan College of Engineering, Tiruchirappalli.
vaijuanand123@gmail.com

M.Bhuvaneshwari,

[2]Associate Professor, Department of Electronics and Communication Engineering, Indra Ganesan College of Engineering, Tiruchirappalli.

P.Subharajam,

[3] Professor, Department of Information Technology, Indra Ganesan College of Engineering, Tiruchirappalli.

V Saravanan,

[4]Professor, Department of Physics, Indra Ganesan College of Engineering, Tiruchirappalli.

K.Uthra Devi,

[5]Assistant Professor, Department of Computer Science Engineering, Indra Ganesan College of Engineering, Tiruchirappalli.

S.Tamil,

[6] Professor, Electronics and Communication Engineering, P.T.Lee Chengalvaraya Naicker College of Engineering & Technology, Kanchipuram.

Abstract

Recent advancements in 5G technology emphasize the need for enhanced spectral efficiency to achieve higher data rates. In current mobile communication systems, cyclic-prefix-based Orthogonal Frequency Division Multiplexing (CP-OFDM) is predominantly used. However, in 4G technology, the cyclic prefix presents a significant drawback, as it leads to symbol rate duplication, thereby reducing efficiency.

To address these limitations, 5G has adopted the Filter Bank Multi-Carrier (FBMC) modulation technique. This method utilizes a specially designed prototype filter to enhance data rates. Unlike OFDM, FBMC effectively suppresses side lobes, resulting in improved spectral efficiency. Consequently, FBMC offers a promising solution for next-generation mobile communication systems.

Keywords: Filter bank Multicarrier, Cyclic Prefix, Spectral Efficiency

INTRODUCTION

Filter Bank Multi-Carrier (FBMC) was considered as an alternative waveform to Orthogonal Frequency Division Multiplexing (OFDM) during the 3GPP RAN Study Phase I in 3GPP Release 14. Recent developments in fifth-generation (5G) wireless communications have further increased interest in exploring alternatives to traditional OFDM systems. This growing shift is primarily due to the limitations of OFDM in dynamic and multi-user network environments, which are characteristic of future wireless systems.

The 5GNOW project has identified four alternative waveforms to better address the demands of 5G. These waveforms, all incorporating some form of filtering, can be viewed as adaptations of the FBMC method to cater to diverse application needs.

This paper focuses on the recent research contributions of the author and their students. It highlights the various shortcomings of OFDM in meeting the requirements of next-generation wireless systems. Additionally, it presents a method for designing FBMC systems that achieve near-optimal performance in doubly dispersive channels, demonstrating the superior performance of FBMC over OFDM.

International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 7 Issue: 12
***Article Received:** 25 July 2019 **Revised:** 12 September 2019 **Accepted:** 30 November 2019*

Over the years, FBMC theory, particularly Cosine Modulated Multitone (CMT) and Staggered Modulated Multitone (SMT), has evolved through extensive research. Early studies typically analyzed these waveforms in terms of continuous-time signals, while more recent research has explored their discrete-time formulations and proposed conditions for Inter-Symbol Interference (ISI) and Inter-Carrier Interference (ICI) cancellation. Notably, the author and their group have revisited classical continuous-time approaches, presenting simplified theoretical concepts and clarifying the relationship between CMT and SMT waveforms.

This continuous-time approach offers significant advantages in designing prototype filters for realizing CMT and SMT systems. To provide a comprehensive understanding, the paper also discusses the underlying theory using a time-frequency phase-space perspective, minimizing complex mathematical derivations.

PROPOSED SYSTEM

Filter Bank Multi-Carrier (FBMC) is an emerging waveform technique that offers several advantages over Orthogonal Frequency Division Multiplexing (OFDM), making it a strong contender for 5G applications. The primary distinction lies in the replacement of OFDM with a multi-carrier system that utilizes filter banks at both the transmitter (TX) and receiver (RX). Several key differences between OFDM and FBMC are highlighted below:

Cyclic Prefix (CP) Extension:

OFDM: Requires a cyclic prefix (CP) extension, which reduces bandwidth (BW) efficiency.

FBMC: Does not require a cyclic prefix, thereby conserving bandwidth.

Side Lobe Suppression:

OFDM: Exhibits large side lobes, leading to spectral leakage and reduced spectral efficiency.

FBMC: Utilizes a prototype filter to effectively suppress side lobes, resulting in better spectral efficiency.

Subcarrier Filtering and Placement:

OFDM: Lacks accurate subcarrier placement and suffers from adjacent subcarrier interference.

FBMC: Applies filtering to individual subcarriers, ensuring precise placement and reducing interference. This makes FBMC well-suited for supporting multiple simultaneous users on a single RF channel, as each user is assigned a distinct set of subcarriers.

Multiple Access Interference (MAI) Cancellation:

OFDM: Requires additional processes for MAI cancellation at the receiver to ensure correct detection.

FBMC: MAI is inherently suppressed due to the excellent frequency localization of its subcarriers.

Carrier Frequency Offset (CFO) Sensitivity:

OFDM: Highly sensitive to carrier frequency offset, leading to degraded performance in high-mobility scenarios.

FBMC: Less sensitive to CFO, maintaining robust performance even with increased user mobility.

Spectrum Sensing:

OFDM: Suffers from degraded spectrum sensing performance due to spectral leakage.

FBMC: Provides high-resolution spectrum sensing, making it advantageous for cognitive radio applications.

Overall, FBMC's enhanced spectral efficiency, reduced interference, and improved robustness in dynamic environments make it a promising choice for next-generation 5G wireless communication systems.

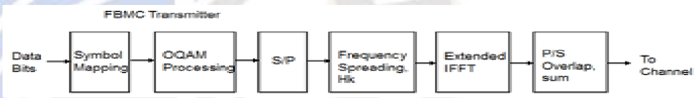


Fig1: FMBC Transmitter

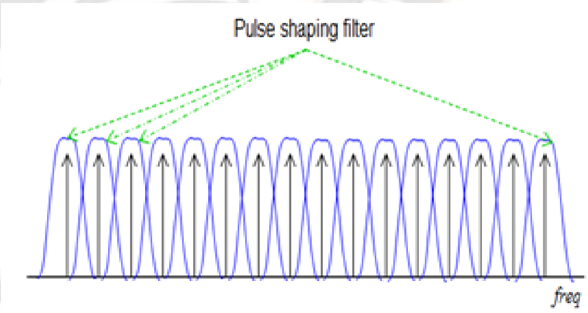


Fig 2: Pulse Shaping of FBMC Filter

Filter Bank Multi-Carrier (FBMC) involves critical steps, primarily focusing on the implementation of filters for individual subchannels and aligning them into a filter bank. The construction of the filter bank begins with the design of a basic filter template known as the prototype filter. Once the prototype filter is designed, it serves as a foundation for the entire FBMC system.

This study proposes an efficient method for designing the prototype filter specifically for FBMC/OQAM systems. The proposed design considers the influence of both channel estimation and stop-band energy. Additionally, a novel

International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 7 Issue: 12
***Article Received:** 25 July 2019 **Revised:** 12 September 2019 **Accepted:** 30 November 2019*

preamble structure is introduced to enhance channel estimation accuracy while preserving spectral efficiency.

To further optimize the design process, an improved genetic algorithm (GA) is implemented. The enhanced algorithm features a History Network and a pruning operator to accelerate convergence and ensure a globally optimal solution. Simulation results validate the effectiveness and efficiency of the proposed prototype filter.

Both OFDM and FBMC are classified as multicarrier techniques, where data symbols are transmitted simultaneously over multiple frequency subcarriers. This multicarrier nature provides inherent support for frequency-selective link adaptation. However, the primary distinction between the two lies in the application of pulse shaping at each subcarrier.

Most of the modern wireless mobile communication technologies are based on OFDM. In contrast, FBMC serves as an advancement of OFDM, with the major structural change being the replacement of the Cyclic Prefix (CP) with a filter bank-based multicarrier system. This design choice significantly enhances spectral efficiency and system performance, making FBMC a promising candidate for next-generation wireless communication systems.

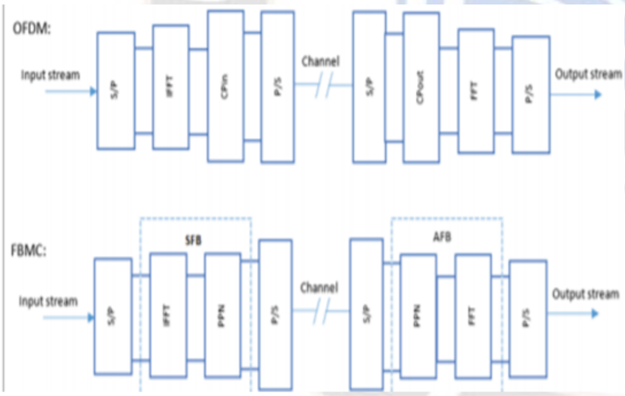


Fig 3 : Comparison of OFDM and FBMC

Filter Bank Multi-Carrier (FBMC) offers significant advantages over **Orthogonal Frequency Division Multiplexing (OFDM)** by eliminating the need for a **Cyclic Prefix (CP)**. This results in a more effective use of radio resources and better spectral containment of signals.

A **filter bank** in FBMC is defined as an array of **N filters** that process **N input signals** to generate **N outputs**. In this system, two types of filter banks are employed:

- **Analysis Filter Bank (AFB)** – Used at the receiver to analyze the received signals.
- **Synthesis Filter Bank (SFB)** – Used at the transmitter to synthesize the transmitted signals.

FBMC systems are a subclass of Multicarrier (MC) systems, where synthesis and analysis filters are applied at the transmitter and receiver, respectively. These filters are typically bandpass filters created by shifting or modulating a prototype low-pass filter. The design of the prototype filter is crucial as it directly influences the spectral containment of the signals.

Advantages of FBMC over OFDM

Spectral Containment:

FBMC achieves better spectral containment than OFDM by allowing the prototype filter's bandwidth and selectivity to be optimized during its design.

Bandwidth Efficiency:

Unlike OFDM, which requires a CP extension that reduces bandwidth efficiency, FBMC conserves bandwidth by eliminating the need for a CP.

Carrier Frequency Offset (CFO) Sensitivity:

OFDM is highly sensitive to CFO, leading to performance degradation. On the other hand, FBMC is less sensitive to CFO, making it more robust in mobile network environments.

Synthesis-Analysis Filter Bank in Multicarrier Systems

FBMC systems can be represented using a trans-multiplexer structure consisting of:

Synthesis Filter Bank (SFB) – Formed by the parallel transmit filters.

Analysis Filter Bank (AFB) – Composed of matched receive filters.

OFDM commonly utilizes Inverse Fast Fourier Transform (IFFT) and Fast Fourier Transform (FFT) for its synthesis and analysis filter banks. The prototype filter in OFDM is a rectangular window, with a size equivalent to the FFT duration.

Preamble-Based Burst Approach

To ensure flexible frequency and time block allocation, a preamble-based burst approach is adopted in FBMC. The preamble, consisting of P-FBMC symbols (with P = 4 in the given example), is used for accurate burst detection and channel frequency response estimation.

Proposed Prototype Filter Design for FBMC/OQAM

This study proposes a novel prototype filter design for FBMC/OQAM systems, taking into account both channel

International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 7 Issue: 12
***Article Received:** 25 July 2019 **Revised:** 12 September 2019 **Accepted:** 30 November 2019*

estimation and stop-band energy. Additionally, an efficient preamble structure is introduced to enhance channel estimation performance while preserving spectral efficiency.

To further accelerate convergence and achieve a global optimal solution, an improved genetic algorithm is proposed. This algorithm incorporates:

History Network – Tracks previously explored solutions.

Pruning Operator – Eliminates unpromising solutions to improve efficiency.

Simulation results validate the effectiveness and efficiency of the designed prototype filter.

Frequency Domain FBMC Receiver

To fully exploit the advantages of FBMC, effective frequency domain receiver algorithms are essential. A practical implementation for an FBMC receiver in the frequency domain has been proposed, demonstrating significant reductions in out-of-band leakage through the plotted Power Spectral Density (PSD) of the FBMC transmit signal.

This study highlights the superior performance of FBMC in terms of spectral efficiency, channel estimation, and robustness, making it a promising solution for next-generation wireless communication systems.

OFDM MODULATION WITH CORRESPONDING PARAMETERS

Comparison of OFDM and FBMC

For comparison purposes, we first review the existing OFDM modulation technique, which uses the entire occupied bandwidth without a cyclic prefix (CP). When analyzing the spectral density plots of OFDM and FBMC schemes, it is evident that FBMC exhibits significantly lower side lobes. This improved spectral containment allows for more efficient utilization of the allocated spectrum, resulting in enhanced spectral efficiency.

FBMC Receiver Without a Channel

This example demonstrates a basic FBMC demodulator and evaluates the Bit Error Rate (BER) for a selected configuration in the absence of a channel. The receiver processing involves the following steps:

Matched Filtering: Applied to the received signal to optimize detection.

OQAM Separation: The received data symbols are separated using Offset Quadrature Amplitude Modulation (OQAM) techniques.

De-Mapping to Bits: The separated symbols are then de-mapped to retrieve the original bits.

BER Calculation: The bit error rate is calculated to assess performance.

Handling Frequency-Selective Fading

In practical scenarios where a channel is present, linear multi-tap equalizers can be applied at the receiver to mitigate the effects of frequency-selective fading. These equalizers compensate for channel distortions and improve the overall system performance.

The following diagram illustrates the receive-end processing in an FBMC system, highlighting the step-by-step signal flow from the input to the final BER calculation.

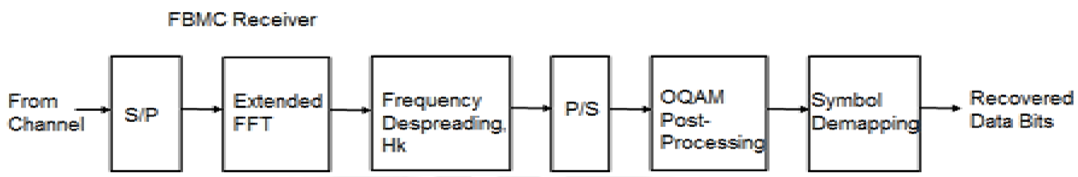


Fig 4: FBMC Receiver

Quadrature Amplitude Modulation (QAM) in Communication Systems

Quadrature Amplitude Modulation (QAM) is widely utilized in various data communication applications and digital radio communications. Common forms of QAM include 16QAM, 32QAM, 64QAM, 128QAM, and 256QAM.

In QAM, two carrier signals, shifted by 90° in phase, are modulated. The resulting output exhibits both phase and amplitude variations, making it a combination of amplitude and phase modulation.

Future 5G mobile communication technology will predominantly use 256QAM due to its superior data representation capability compared to 64QAM. Higher QAM numerology allows for the transmission of more data using the same number of symbols, resulting in increased spectral efficiency.

Comparison of OFDM and FBMC Systems

International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 7 Issue: 12
***Article Received:** 25 July 2019 **Revised:** 12 September 2019 **Accepted:** 30 November 2019*

Despite the simple concept and low complexity of OFDM systems, FBMC has gained attention due to its robustness in various scenarios.

FBMC offers greater resistance to time and frequency offsets than OFDM and eliminates the need for a Cyclic Prefix (CP) extension. This results in more efficient use of bandwidth.

Additionally, FBMC employs signals with high spectral containment to minimize the side lobes of each subcarrier frequency. This reduction in side lobes enhances spectral efficiency and reduces interference, making FBMC a promising alternative for future wireless communication systems.

RESULTS AND DISCUSSION

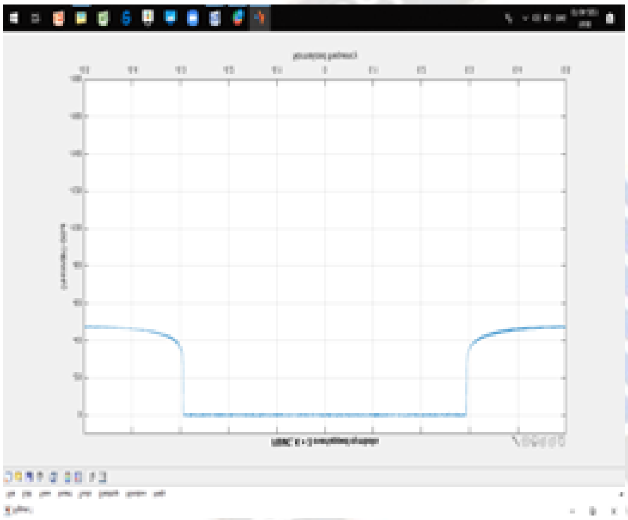


Fig 5: Normalized Frequency of Overlapped Symbols When K=2

The above figure illustrates the overlapped symbols of an FBMC system with a parameter value of K = 2. The X-axis represents the normalized frequency, while the Power Spectral Density (PSD) is plotted to demonstrate the variation in spectral efficiency over time.

The overlapping nature of FBMC symbols is a key characteristic that enhances spectral containment and reduces side lobes, leading to improved spectral efficiency compared to traditional systems. The PSD plot effectively visualizes these improvements, highlighting the system's ability to utilize bandwidth more efficiently.

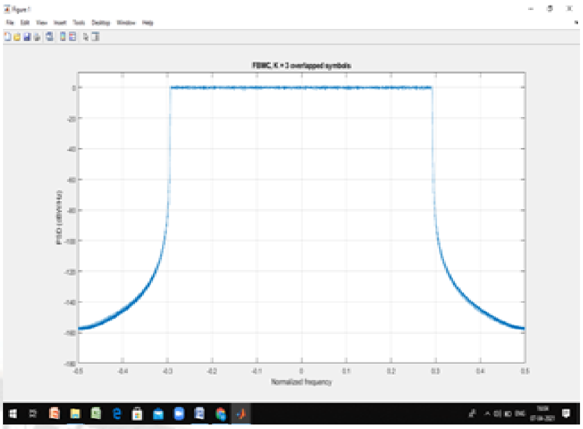


Fig 6: Normalized Frequency of Overlapped Symbols When K=3

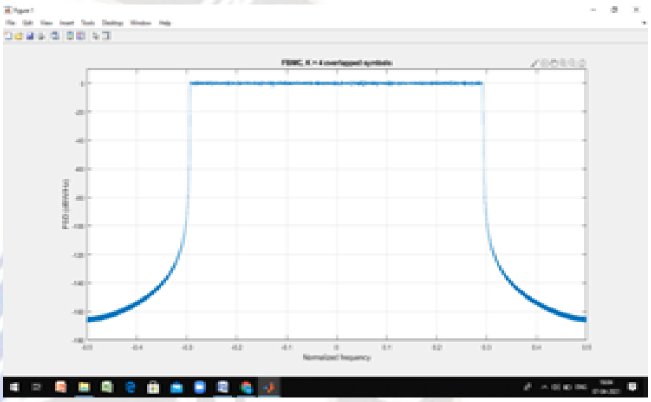
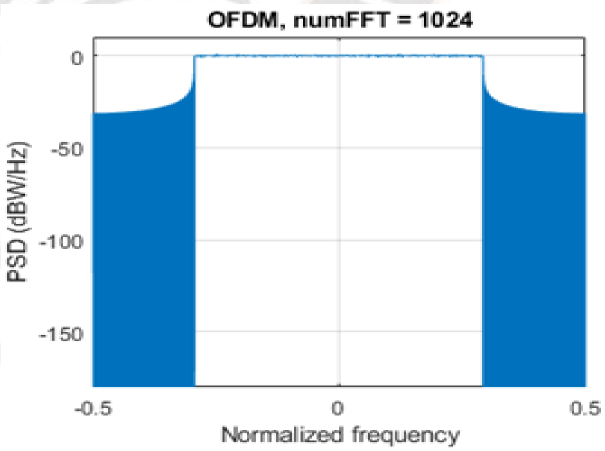


Fig 7: Normalized Frequency of Overlapped Symbols When K=4



The Power Spectral Density (PSD) of the FBMC transmit signal is plotted to emphasize its low out-of-band leakage. When comparing the spectral density plots of OFDM and FBMC schemes, it is evident that FBMC exhibits significantly lower side lobes.

This reduced side lobe effect enables more efficient utilization of the allocated spectrum, resulting in higher spectral efficiency. As a result, FBMC offers a clear advantage over OFDM in terms of minimizing interference and optimizing bandwidth usage.

CONCLUSION

FBMC Modulation: Transmit and Receive Characteristics

This example demonstrates the fundamental transmit and receive characteristics of the FBMC modulation scheme. You can explore various configurations by adjusting parameters such as:

Number of Overlapping Symbols

FFT Lengths

Guard Band Lengths

Signal-to-Noise Ratio (SNR) Values

Advantages of FBMC over OFDM

FBMC offers significant advantages over OFDM, primarily due to its higher spectral efficiency. Unlike OFDM, which requires a Cyclic Prefix (CP) extension that reduces bandwidth efficiency, FBMC eliminates the need for a CP, conserving bandwidth.

Additionally, FBMC applies per-subcarrier filtering, resulting in better spectral containment and reduced interference. However, this approach introduces a larger filter delay compared to UFMC (Universal Filtered Multi-Carrier).

Another key distinction is the requirement for OQAM (Offset Quadrature Amplitude Modulation) processing in FBMC. While this enhances spectral efficiency, it necessitates specific adjustments for MIMO (Multiple Input Multiple Output) systems.

Moreover, OFDM is highly sensitive to Carrier Frequency Offset (CFO), leading to performance degradation. In contrast, FBMC is more robust to CFO, making it a reliable choice for next-generation communication systems.

References

[1] B. Farhang-Boroujeny, "OFDM Versus Filter Bank Multicarrier," *IEEE Signal Processing Magazine*, vol. 28, no. 3, pp. 92-112, May 2011.

[2] M. Bellanger, "FBMC Physical Layer: A Primer," *ETSI Technical Report*, 2012.

[3] G. Fettweis and S. Alamouti, "5G: Personal Mobile Internet Beyond What Cellular Did to Telephony," *IEEE Communications Magazine*, vol. 52, no. 2, pp. 140-145, February 2014.

[4] H. Lin, P. Siohan, and R. Legouable, "Channel Estimation for FBMC/OQAM Systems: A Review," *IEEE Transactions on Signal Processing*, vol. 66, no. 5, pp. 1201-1216, March 2018.

[5] 3GPP, "Study on New Radio (NR) Access Technology," *3GPP TR 38.912*, Release 14, March 2017.

[6] B. Farhang-Boroujeny, "Filter Bank Multicarrier Modulation: A Waveform Candidate for 5G," *Advances in Electrical and Computer Engineering*, vol. 17, no. 3, pp. 17-26, 2017.

[7] Hassan et al., "5G Waveform Competition: Performance Comparison and Analysis of OFDM and FBMC in Slow Fading and Fast Fading Channels," in *Proceedings of the 2018 International Conference on Communications*, 2018, pp. 45-50.

[8] Y. Qi and M. Al-Imari, "An Enabling Waveform for 5G - QAM-FBMC: Initial Analysis," *arXiv preprint arXiv:1803.03169*, 2018.

[9] Aminjavaheri, A. Farhang, A. RezazadehReyhani, and B. Farhang-Boroujeny, "Impact of Timing and Frequency Offsets on Multicarrier Waveform Candidates for 5G," *arXiv preprint arXiv:1505.00800*, 2015.

[10] M. Bellanger, "FS-FBMC: An Alternative Scheme for Filter Bank Based Multicarrier Transmission," in *Proceedings of the 2012 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 2012, pp. 4785-4788

[11] G. Wunder et al., "5GNOW: Non-Orthogonal, Asynchronous Waveforms for Future Mobile Applications," *IEEE Communications Magazine*, vol. 52, no. 2, pp. 97-105, February 2014.

[12] H. Lin and P. Siohan, "Multi-Carrier Modulation Analysis and WCP-COQAM Proposal," *EURASIP Journal on Advances in Signal Processing*, vol. 2014, no. 1, pp. 1-18, December 2014.

[13] 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, March 2012.