OFDM Systems: Timing Synchronization Hardware Implementation Method

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Abstract

This research presents a timing synchronization hardware implementation method suitable for Orthogonal Frequency Division Multiplexing (OFDM) systems. The method ensures compatibility with the IEEE 802.11a/g/n protocols and enhances the accuracy of cyclic shift processing in the IEEE 802.11n protocol. A robust frame detecting algorithm is devised, employing cluster peak detection and instantaneous peak detection to improve the accuracy of data detection. Coarse and fine frequency offset estimations are performed using two self-correlation modules and a moving average module, respectively, to achieve a comprehensive frequency offset estimation. An improved CORDIC algorithm is utilized for frequency offset correction, enhancing operational efficiency.

Keywords: Timing synchronization, OFDM system, IEEE 802.11a/g/n, cyclic shift, frame detection, frequency offset estimation, CORDIC algorithm.
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Introduction

Wireless communication systems have witnessed significant advancements in recent years, enabling efficient and reliable transmission of data. Orthogonal Frequency Division Multiplexing (OFDM) is a key technology widely employed in modern wireless communication systems, including the popular IEEE 802.11a/g/n protocols. OFDM divides the available bandwidth into multiple subcarriers, each carrying a portion of the data. This division enhances system performance by mitigating the effects of multipath fading and improving spectral efficiency(Assaidah et al. 2020; Khalid 2020; Kishore, Prasad, and Vakmulla 2020).

In an OFDM system, accurate timing synchronization is crucial for maintaining reliable communication. Timing synchronization ensures that the receiver can correctly sample the transmitted signal and recover the transmitted data accurately. It plays a critical role in mitigating the adverse effects of frequency offset, timing jitter, and channel distortion, which can degrade the system's performance(Touhami et al. 2020).

One of the significant challenges in timing synchronization is achieving accurate synchronization in the presence of various environmental factors and protocol requirements. The IEEE 802.11a/g/n protocols are widely adopted for wireless local area networks (WLANs) and require specific synchronization mechanisms to ensure seamless communication. Moreover, the IEEE 802.11n protocol introduces the concept of cyclic shift processing, which poses additional challenges for timing synchronization in OFDM systems.To address these challenges, this research focuses on developing a hardware implementation method for timing synchronization in OFDM systems that is applicable to the IEEE 802.11a/g/n protocols(Wu and Fan 2015).

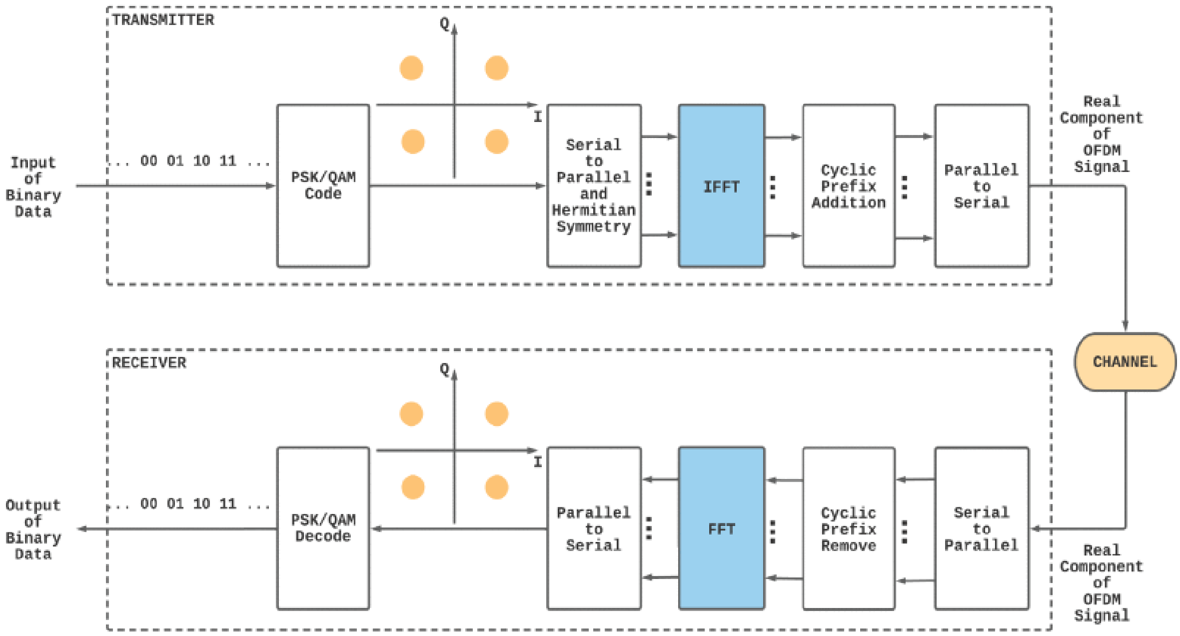

Figure 1. Block diagram of OFDM system with hermitian symmetry.

Figure 1 illustrates a general Visible Light Communication (VLC) system employing an Orthogonal Frequency Division Multiplexing (OFDM) scheme with Hermitian Symmetry. The system comprises two primary components: the transmitter and the receiver. The transmitter takes input binary data and generates quadrature amplitude modulated (QAM) or phase-shift keying (PSK) samples. These samples are then utilized to construct vectors that exhibit Hermitian Symmetry and undergo Inverse Fast Fourier Transform (IFFT) to form OFDM symbols. To mitigate the impact of Inter-Symbol Interference (ISI), a guard interval is implemented. The common approach involves utilizing a Cyclic Prefix (CP), where a copy of the symbol's end is appended to the beginning. The length of this guard interval must exceed the maximum transmission delay of the channel to eliminate ISI and preserve orthogonality(Kishore et al. 2020).

The research aims to improve the accuracy and efficiency of timing synchronization, particularly in the context of cyclic shift processing.The primary research objective is to design a timing synchronization method that ensures compatibility with the IEEE 802.11a/g/n protocols. Specifically, the method will address the requirements of cyclic shift processing in the IEEE 802.11n protocol. Cyclic shift processing involves shifting the transmitted signal's subcarriers to improve synchronization accuracy, especially in the presence of frequency offsets. By developing a method that is compatible with the IEEE 802.11a/g/n protocols, this research seeks to contribute to the advancement of timing synchronization techniques in OFDM-based wireless communication systems(Saemi et al. 2006).

The proposed method incorporates several key components to achieve accurate timing synchronization. First, a robust frame detecting algorithm is designed to enhance the accuracy of data detection. This algorithm utilizes cluster peak detection and instantaneous peak detection to determine whether data is present, thereby improving the judgment accuracy. Accurate data detection is crucial for reliable synchronization and subsequent data recovery(Assaidah et al. 2020).

Additionally, the method employs a two-step frequency offset estimation approach. Coarse frequency offset estimation is performed using self-correlation modules, which provide an initial estimation of the frequency offset.

Fine frequency offset estimation, on the other hand, utilizes a moving average module to refine the estimation further. By combining coarse and fine frequency offset estimations, the method aims to achieve comprehensive frequency offset estimation, thereby enhancing synchronization accuracy(Touhami et al. 2020).

To correct the estimated frequency offset, the proposed method adopts an improved CORDIC (Coordinate Rotation Digital Computer) algorithm. CORDIC algorithms are widely used for trigonometric function calculations and have been extended to various applications in signal processing. The improved CORDIC algorithm ensures efficient and accurate frequency offset correction, contributing to the overall operational efficiency of the timing synchronization process.To evaluate the effectiveness of the proposed hardware implementation method, the research will conduct simulation tests. These tests will involve implementing the method on wireless sensor networks with varying scales and operating conditions. The simulation tests will assess the accuracy, efficiency, and compatibility of the proposed method, providing insights into its performance and potential improvements(Inguva and Seventiline 2019).

In conclusion, accurate timing synchronization is vital for the reliable operation of OFDM-based wireless communication systems. This research aims to develop a hardware implementation method for timing synchronization in OFDM systems that is compatible with the IEEE 802.11a/g/n protocols. The method incorporates a robust frame detecting algorithm, coarse and finefrequency offset estimations, and an improved CORDIC algorithm for frequency offset correction. The objective is to enhance the accuracy and efficiency of timing synchronization, particularly in the context of cyclic shift processing in the IEEE 802.11n protocol. Through simulation tests conducted on wireless sensor networks with varying scales, the proposed method will be evaluated to assess its compatibility, accuracy, and operational efficiency(Fuada, Putra, and Adiono 2022).

Related Work

OFDM (Orthogonal Frequency Division Multiplexing) is a multi-carrier modulation technology widely used in high-speed wireless access transmission, including the IEEE 802.11a/g/n protocols. It allows for the efficient utilization of frequency spectrum resources by converting high-rate data streams into parallel subcarriers, increasing the persistence length of data symbols on each subcarrier and effectively combating inter-symbol interference. This technology has significantly improved transmission efficiency in wireless communication systems.As evident in **Figure 2,** the proposed method incorporates a pre-FFT synchronization phase wherein the detection of the initiation of the OFDM packet takes place. A novel aspect introduced in this study is the inclusion of a time correction procedure achieved by eliminating the cyclic prefix (CP). This process involves estimating the phase offset during a post-FFT fine synchronization phase(Kishore et al. 2020).

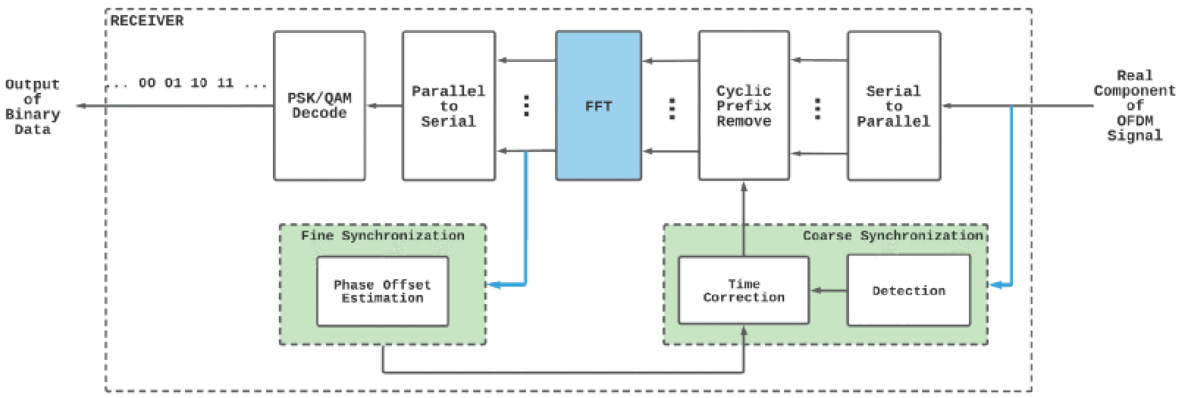

Figure 2. Time synchronization for OFDM system with hermitian symmetry.

However, in the process of data transmission, OFDM technology is susceptible to frequency offsets, which can disrupt the orthogonality between subcarriers. The impact of multi-path interference in real-world environments further exacerbates this issue. Therefore, it is crucial to have robust synchronization modules in OFDM systems to mitigate interference and ensure reliable data transmission.Synchronization in OFDM systems can be achieved through data-assisted synchronization algorithms or blind synchronization algorithms. Data-assisted synchronization algorithms require the insertion of training sequences, which reduce the data transmission rate but offer high estimation accuracy and low computational complexity. Coarse frequency offset estimation is conducted by exploiting the periodicity and correlation between the training sequences and the received signal, enabling frame synchronization. Additionally, the received signal strength and local Long Training Field (LTF) can be used for fine frequency offset estimation through computing cross-correlation. While data-assisted synchronization methods have low complexity and are easily implementable in hardware, the smoothness of the target function for time synchronization may limit their effectiveness(Saemi et al. 2006).

On the other hand, blind synchronization methods do not rely on additional training sequences and provide a higher bandwidth utilization ratio. However, they come with higher computational complexity. For instance, the Cyclic Prefix-based blind synchronization method proposed by Van de Beek restricts the frequency offset estimation range to half the subcarrier spacing, which may result in inaccuracies in time synchronization under multipath fading conditions.For hardware implementations of synchronization algorithms, FPGA (Field-Programmable Gate Array) is commonly used as a semi-custom circuit development platform. However, FPGA resources are limited, and the hardware implementation of synchronization algorithms requires significant gate resources, larger area, and higher power consumption. Therefore, it is essential to seek synchronization algorithms with low complexity, high accuracy, and efficiency while utilizing FPGA resources most effectively(Assaidah et al. 2020).

In the case of the IEEE 802.11n protocol, with a maximum bandwidth of 40 MHz, the design of synchronization hardware algorithm modules must operate at frequencies higher than 40 MHz. Additionally, the presence of cyclic shift introduces deviations during sign synchronization in conventional synchronization hardware algorithms. To address these challenges, it is necessary to develop synchronized algorithms that involve phase angle computation, improve the processing speed while ensuring performance, reduce the required floor area, enhance efficiency, and improve compatibility under the IEEE 802.11n protocol(Wu and Fan 2015).

In summary, OFDM technology has revolutionized wireless communication systems by enabling efficient data transmission. However, timing synchronization remains a critical aspect of OFDM systems. This research aims to develop a timing synchronization hardware implementation method applicable to OFDM systems, specifically targeting compatibility with the IEEE 802.11a/g/n protocols. The research addresses challenges related to cyclic shift processing, frequency offset estimation, and algorithm efficiency to improve the performance and compatibility of synchronization in high-speed wireless communication systems.

Research Objective

The research aims to develop a hardware implementation method to address timing synchronization challenges in OFDM (Orthogonal Frequency Division Multiplexing) systems. The specific objectives of this research are outlined below:

1. Compatibility with IEEE 802.11a/g/n protocols: The proposed method should be compatible with these protocols commonly used in wireless

communication. It should be able to handle the cyclic shift processing requirements specific to the IEEE 802.11n protocol.

2. Robust frame detecting algorithm: A reliable algorithm needs to be designed to accurately detect the presence of data in the received signal. This will be achieved by utilizing cluster peak detection and instantaneous peak detection techniques, which improve the accuracy of determining whether data is present or not.
3. Improved accuracy of frequency offset estimation: The research aims to enhance the accuracy of estimating frequency offsets, which can be caused by factors such as multipath interference. To achieve this, two self-correlation modules will be used for coarse frequency offset estimation, while a moving average module will be employed for fine frequency offset estimation.
4. Comprehensive frequency offset estimation: The relationship between coarse and fine frequency offset estimations will be considered to obtain a comprehensive estimation of the frequency offset. By combining the results from both estimation methods, a more accurate estimation of the frequency offset can be achieved.
5. Implementation of an improved CORDIC algorithm: The research intends to utilize an improved version of the CORDIC (Coordinate Rotation Digital Computer) algorithm for frequency offset correction. This algorithm will enhance the efficiency of the correction process, ensuring that frequency offsets are accurately compensated for.

By accomplishing these research objectives, the proposed hardware implementation method for timing synchronization in OFDM systems aims to enhance the performance and efficiency of wireless communication. It will contribute to the development of more reliable and accurate synchronization techniques, which are crucial for ensuring the effective transmission and reception of data in OFDM-based communication systems.

Timing Synchronization Hardware Implementation Method for OFDM Systems

A timing synchronization device for MIMO OFDM (Multiple-Input Multiple-Output Orthogonal Frequency Division Multiplexing) systems has been developed. This device is designed to address the challenges of achieving accurate timing synchronization in MIMO OFDM systems.The timing synchronization device consists of four main units: the Frame Synchronization Test unit, the coarse frequency offset unit, the sign synchronization detecting unit, and the fine frequency deviation estimating unit. Each unit plays a specific role in achieving precise timing synchronization.The frame synchronization algorithm used in this device is based on the time delay auto-correlation algorithm. It utilizes a preamble sequence, which is a specific pattern inserted at the beginning of data transmission according to the IEEE802.11 serial protocols. By applying the auto-correlation algorithm to the received signal, the device can detect the frame signal accurately.

Sign synchronization, on the other hand, employs a cross-correlation algorithm. It utilizes the long training sequence embedded in the leading code of the OFDM signal. This allows the device to achieve meticulous sign synchronization, ensuring the accurate alignment of the received signal with the reference signal.

For frequency offset estimation, both coarse and fine frequency deviations are estimated using the CORDIC (Coordinate Rotation Digital Computer) algorithm. The CORDIC algorithm takes into account the relationship between coarse frequency offset estimation and fine frequency deviation estimation. By combining these estimates, the device can obtain the final frequency shift (FS), which represents the precise frequency offset of the received signal.

Overall, this timing synchronization device for MIMO OFDM systems combines various algorithms and techniques to achieve accurate timing synchronization. The frame synchronization test, coarse frequency offset estimation, sign synchronization detection, and fine frequency deviation estimation units work together to ensure reliable and precise synchronization in MIMO OFDM communication.

Conclusion

In conclusion, this research proposes a timing synchronization hardware implementation method tailored for OFDM systems. The method successfully addresses the compatibility challenges posed by the IEEE 802.11a/g/n protocols and effectively processes the cyclic shift requirements of the IEEE 802.11n protocol, resulting in more accurate synchronous data. The devised robust frame detecting algorithm significantly improves the judgment accuracy of received data. Coarse and fine frequency offset estimations are performed using dedicated modules, leading to enhanced accuracy in frequency offset estimation. The utilization of an improved CORDIC algorithm for frequency offset correction improves operational efficiency. Overall, the proposed method contributes to the advancement of timing synchronization in OFDM systems, facilitating reliable and efficient data transmission.

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