A modified Timing Metric for Timing Synchronization in NC-OFDM System

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Research Article

Keywords: OFDM, NC-OFDM, Cognitive Radio, timing metric

Posted Date: September 20th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-943211/v1

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Abstract

In a traditional method of timing synchronization in the OFDM system, data on regularly spaced subcarriers are transmitted. However, the concept of data transmission on regular spaced subcarriers does not fulfill the requirement of cognitive radio (CR) system in achieving dynamic spectrum management, free from interference from the primary users. So, Non-Contiguous OFDM (NC-OFDM) is considered for CR to support high data rate transmission in a wireless environment, it overcomes multipath delay spread. NC-OFDM system has high spectrum efficiency, so it is useful for CR system. Several synchronization schemes have been explored for the OFDM system. However, these schemes are not appropriate for NC-OFDM system as these schemes do not use deactivated subcarriers. In this paper, a modified timing metric for the timing synchronization in NC-OFDM based CR system is proposed. The performance of the proposed timing synchronization scheme is compared with the traditional Park and Zhang schemes.

1. Introduction

In recent times, with the development of wireless technology, the numbers of wireless applications and users have increased exponentially. The use of available spectrum for wireless application has almost reached its threshold. CR [1][2] system has drawn considerable attention to overcome scarcity of spectrum. CR system detects the availability of unused licensed spectrum specified for primary user and allows the same spectrum for the use of un-licensed secondary user [3]. CR network aggregates fragmented bands of un-used spectrum of primary user so as to support wideband services. Thus the band of spectrum utilized by CR system to support wideband services is noncontiguous [1][4][7]. OFDM is a multicarrier modulation technique suitable to provide wideband wireless service due to its capability to combat multipath fading effects [8]. Usually data in an OFDM system modulates subcarriers which occupy contiguous spectrum. However, OFDM has the ability to modulate sub-carriers which are non-contiguous. Thus, NC-OFDM transmission technology is found to be suitable for CR network. IEEE 802.22 is a Wireless Regional Area Network (WRAN) standard which utilizes NC-OFDM based CR concept and use white space in TV spectrum [9][10].

NC-OFDM is a useful transmission technology able to detect fragmented band of frequencies and modulate non-contiguous subcarriers. In an NC-OFDM system, any of the subcarriers can be deactivated depending upon the occupied frequency of primary user of a CR communication system. Since OFDM technology has the ability to support high data rate in wireless environment, NC-OFDM based CR provides broadband wireless service in CR network [11]. However, similar to OFDM, synchronization error in NC-OFDM system also results in severe performance degradation.

Schmidl [12], Minn [13] and Park [14] are few of the pilot aided synchronization schemes proposed for the synchronization in OFDM system. The traditional OFDM timing synchronization schemes [12], [13] and [14], which utilizes continuous subcarrier is not suitable for NC-OFDM based CR system. So, there is a need of suitable timing synchronization scheme for NC-OFDM system suitable for CR application.
A timing synchronization scheme for NC-OFDM system presented by Zhang [9] consists of OFDM symbol with repeated identical sequences in time domain. The symbol is generated due to random deactivated subcarrier in frequency domain. The scheme produces small side lobe in the timing metric due to the higher value of inner products. This results in the poor timing synchronization performance in multipath fading channel. Zadoff-Chu proposed a sequence where instead of PN sequence in the time domain a preamble is suggested but as discussed in [9] Zadoff-Chu sequence is not preferable for NC-OFDM system.

In this paper, a modified timing metric is proposed for timing synchronization which reduces the side lobe and improves the timing synchronization failure. The rest of the paper is organized as follows. Section 2 describes Timing Synchronization in NC-OFDM System. Section 3 describes proposed timing metric. Results and interpretation is presented in Section 4. The paper is concluded in Section 5.

2. Timing Synchronization In Nc Ofdm System

OFDM has been used to support high data rate services due to its robustness to multipath fading. Due to spectrum scarcity, NC-OFDM based cognitive radio is an alternate option to support high data rate services. However, similar to OFDM system, NC-OFDM is highly sensitive to synchronization error. Autocorrelation between identical parts of a time domain OFDM symbol is mostly adopted for timing synchronization in OFDM system. The time-domain sequence having repeated parts for classical synchronization schemes of OFDM systems is obtained using the PN sequence in even frequencies of IFFT.

In all the classical timing synchronization schemes, identical parts in time domain OFDM symbol are obtained due to the presence of data on regularly spaced subcarriers. However, it is not always possible to get continuous carriers to generate OFDM symbol. Thus non-contiguous carriers are considered in NC-OFDM system. Zhang [9] has synchronization scheme for the synchronization in NC OFDM system. It has proposed the generation of new NC-OFDM symbol with repeated identical parts by considering non-contiguous sub-carriers.

2.1. Zhang scheme

The Zhang algorithm generates the synchronization sequence in the frequency domain for the NC-Orthogonal Frequency Division Multiplexing system as described below.

1. $X(k)$ represents the pseudo-random sequence assigned to the positive frequency, where $k=0,1,\ldots,(N/2)-1$
2. $X(k)$ for the negative frequencies ($k= -N/2,\ldots,-1$) is given as

$$X(k) = \begin{cases} X(-k-1), & k = -2i \\ -X(-k-1), & k = -2i+1, i = 1,2,\ldots,\frac{N}{4} \end{cases}$$
1. The activation vector $p(k)$ is set to be 1, if the $k$-th subcarrier is active. $p(k)$ is set to be zero, if $k$-th subcarrier is deactivated.

2. The data on $k$-th frequency domain subcarrier is expressed as

$$X(k) = p(k) p(-k) X(k), k = -\frac{N}{2}, \ldots, \frac{N}{2} - 1$$

1. $x(m)$ represents the $m$-th time domain synchronization sequence generated due to the IFFT operation.

The final sequence $x(n)$ is obtained with the assumption that $n = m + (N/2)$.

1. The time domain structure of $x(n)$ is obtained as

$$x(n) = \left[ aC\bar{b}\bar{C} a^* C^* b^* \bar{C}^* \right], \text{where, } x(n) \text{ has the property of Park's scheme.}$$

The timing metric used by Zhang scheme to determine the start of the NC-OFDM symbol is given as

$$M_{Zhang}(\alpha) = \frac{|P_{Zhang}(\alpha)|^2}{R_{Zhang}^2(\alpha)}$$

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where,$P_{Zhang}(\alpha) = \sum_{k=0}^{N/2-1} r(\alpha - k) \cdot r(\alpha + k) \quad (2)$

and,$R_{Zhang}(\alpha) = \sum_{k=0}^{N/2-1} |r(\alpha + k)|^2 \quad (3)$

It is observed that the denominator of timing metric is the energy of the second half of OFDM symbol.

The mean of the denominator is expressed as,

$$E[R_{Zhangk}(\alpha)] = 2N(\sigma_s^2 + \sigma_n^2) \quad (4)$$

where, $\sigma_s^2$ is the variance of signal and $\sigma_n^2$ is variance of noise.

### 3. Proposed Timing Metric

It is observed from (4) that the mean of the denominator of the timing metric is $2N$ times the sum of variance of signal and noise. So, the mean of the denominator value is high at correct time. This results in the low value of timing metric at correct time. Thus the probability of miss detection ($P_M$) is more.

Further, low timing metric value at correct time leads to lower value in the difference between timing metric value at correct time and side lobe value. This results in the increase of false detection ($P_F$). Due to several false detections, and miss detections, the probability of detection failure ($P_D$) increases.
to decrease $P_D$, it is required to reduce probability of miss detection $P_M$. This can be achieved by increasing the value of timing metric at correct time. In order to increase timing metric value at correct time, we have proposed a new timing metric with modified denominator in (5).

The timing metric at $\alpha$th instant is given by:

$$M_{Proposed} (\alpha) = \frac{|P_{Proposed} (\alpha)|^2}{R_{Proposed}^2 (\alpha)}$$

where, $P_{Proposed} (\alpha) = \sum_{k=0}^{N/2-1} r (\alpha - k) . r (\alpha + k) \quad (6)$

$$R_{Proposed} (\alpha) = \sum_{k=0}^{N/2-1} (|r (\alpha - k)| - |r (\alpha + k)|)^2 \quad (7)$$

It is observed that the denominator of the proposed timing metric is the square of difference of absolute value over $N/2$ samples. In order to determine the performance of the proposed timing metric, we have determined the mean of denominator of timing metric.

Expectation or Mean of the denominator $R_{Proposed}$ can be written as,

$$E[R_{Proposed} (\alpha)] = 2N\sigma_N^2 \quad (8)$$

It is observed from the above equation that the mean of denominator of the proposed scheme depends as the variance of noise only. Since, variance of noise is low; the value of denominator is low. This low value of denominator leads to higher value of timing metric at correct time compared to Zhang’s scheme. The difference between high value of timing metric at correct time and side lobe value increases. This results in the lower value of $P_M$ and $P_F$ compared to Zhang’s scheme and subsequently leads to lower probability of detection failure $P_D$.

The mean of denominator of the timing metric for the Zhang’s scheme and the proposed timing metric is represented in Fig. 1. It represents mean of the denominator v/s SNR for the timing metric due to Zhang and the proposed timing metric. It is observed that the mean of both the schemes decreases with SNR. However, the mean of the denominator for the Zhang’s timing metric is higher than the proposed timing metric by 57.6.

The timing metric of Park, Zhang and the proposed method is shown in the Fig. 2 for AWGN channel distortion. Here Total Subcarrier (N) is 1024 samples, a cyclic prefix (Ncp) is 128 samples and the AWGN transmission Channel is used. The correct Timing index is 1152.
Since at correct timing new timing metric yields a sharp peak which is greater than 1 and negligible side lobe as compared to peak value, it has low miss detection probability. Unlike Park and Zhang scheme where a side lobe appeared at a 640-time index causing false alarm detection, our proposed method has an insignificant side lobe at 640-time index. So it's better than Park and Zhang scheme.

4. Results And Interpretation

In this section we evaluate the performance of the proposed new timing metric and compare the performance with the existing synchronization schemes for NC OFDM system. We have considered an NC OFDM system with 1024 number of sub-carriers (N), CP with 128 samples, normalized carrier frequency offset=0.1 to evaluate the performance of timing synchronization scheme in exponential decaying Rayleigh distributed multipath fading channel. The performance metrics which are used to evaluate the performance are Peak to side lobe ratio, Probability of detection failure and Ratio of deactivated subcarrier.

4.1. Peak-to-side lobe ratio vs. SNR

Peak to Side lobe Ratio (PSR) vs. SNR in dB for the proposed scheme, scheme due to Zhang & Park is presented in Fig. 3. It is an indication of the difference between the timing metric at correct time and the next close timing metric value. Higher is the peak to side lobe ratio better is the performance of the timing synchronization scheme. It is observed from the figure that the PSR for Park, Zhang and the proposed scheme increases with increase in SNR. However, the proposed scheme observed to have a higher PSR of 200 compared to PSR of 10 and 1.75 for Zhang and Park scheme respectively at 10dB SNR. Higher PSR is observed for the proposed scheme due to the absence of side lobe in the timing metric. The PSR for the scheme due to Zhang is lower due to the presence of significant side lobe observed in the timing metric plot.

4.2. Ratio of deactivated subcarrier vs. PSR

In an NC-OFDM system the number of non-availability of sub-carriers varies from time to time. The data on the non-available sub-carriers are made zero. Now it is essential to study the effects of deactivated sub-carriers on the peak to side lobe ratio. Fig. 4 represents PSR v/s no of deactivated sub-carriers for the Park's scheme, Zhang's scheme and the proposed scheme. It is observed that the PSR for Park's scheme is low compared to Zhang's scheme and proposed scheme and the PSR doesn't change with number of deactivated sub-carrier. The PSR for the proposed scheme and Zhang's scheme is higher than Park's scheme by 100 and 10 respectively for a deactivated sub-carrier of 30%.

4.3. Threshold detection

The starting timing of the OFDM symbol is determined to be the sample for which the timing metric is greater than the threshold value. So, it is essential to determine the appropriate threshold value for the estimation. Probability of detection failure is the combination of probability of false alarm detection and probability of miss detection. The probability of detection failure vs. Threshold value is presented in Fig.
5. It is observed from Fig. 6 that the probability of detection failure for Park's and Zhang's schemes is large for low threshold due to higher value of miss detection. The Probability of detection failure decreases with increase in threshold value due to the decrease in the probability of miss detection. This trend continues till the threshold value becomes 0.39 and 0.69 for the Park's and Zhang's scheme respectively. Further increase in threshold value beyond 0.39 and 0.4 for Park's and Zhang's scheme respectively, the probability of detection failure increases due to increase in the false detection. Similar trend for the probability of false and missdetection is also observed in the Fig. 7 for the proposed scheme. The threshold value for minimum probability of false and missdetection is observed to be 3.5 for the proposed scheme. This value is utilized to evaluate the performance.

4.4. Probability of detection failure vs. SNR

Probability of Detection Failure vs. SNR is presented in Fig. 8 for Park's scheme, Zhang's scheme and proposed scheme. It is observed that the probability of detection failure remains unchanged until the SNR of 1dB and 3dB for the scheme due to Zhang and Park respectively. Further increase in SNR, results in a sharp decrease in the probability of detection and it remains unchanged for the SNR value beyond 7dB and 12dB respectively. However, the probability of detection failure for the proposed scheme indicates a sharp decrease with increase in SNR and the probability of detection remains constant with a very low value for the SNR beyond 5dB. It is observed that the probability of detection failure for the proposed scheme is around 0.01 at SNR of 5dB. However, the probability of detection failure for the scheme due to Park and Zhang is around 0.9 and 0.4 respectively. Thus the probability detection of the proposed scheme is better than the schemes due to Park and Zhang.

5. Conclusion

In this paper a modified timing metric for the timing synchronization scheme is proposed for the NC-OFDM based cognitive radio system. The classical timing synchronization schemes are based on correlation between several identical parts in an OFDM symbol generated due to the presence of data on all continuous sub-carriers at the input of the IFFT operation. Classical schemes are not suitable for the cognitive based NC-OFDM based cognitive radio system as all subcarriers are not always available. Zhang et al have proposed generation of NC-OFDM system and used the timing metric due to park. However, the performance is poor due to the presence of significant side lobe. Thus we have proposed a modified timing metric where the denomination of the timing metric proposed by Zhang is the represented as the difference of absolute value of the samples in two identical halves of NC-OFDM symbol. It is observed that the modified timing metric results in the sharp timing metric with very low side lobes compared to the other classical schemes and scheme due to Zhang. The proposed scheme found to have better peak to side lobe ratio. The probability of detection is also observed to be higher than other classical schemes and scheme due to Zhang.

References

**Figures**
**Figure 1**

Mean of denominator of the timing metric for Park vs. Proposed

**Figure 2**

Timing Metric of (a) Park (b) Zhang and (c) Proposed Scheme
Figure 3

Peak-to-Side lobe Ratio vs. SNR in dB (a) Park (b) Zhang and (c) Proposed Scheme
Figure 4

Ratio of Deactivated Subcarrier vs. PSR in dB (a) Park (b) Zhang and (c) Proposed Scheme
Figure 5

Probability of Detection Failure vs. Threshold Values showing the lowest probability of detection failure of the (a) Park and (b) Zhang (c) Proposed Scheme
Figure 6
Probability of Detection Failure vs. Threshold Values showing the lowest probability of detection failure of the (a) Park and (b) Zhang Scheme
Figure 7

Probability of Detection Failure vs. Threshold Values showing the lowest probability of detection failure of the Proposed Scheme
Figure 8

Probability of Detection Failure vs. SNR in dB (a) Park (b) Zhang and (c) Proposed Scheme