TIME SYNCHRONIZATION ERRORS AND ITS MITIGATING TECHNIQUES IN OFDM

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Abstract: Orthogonal Frequency Division Multiplexing (OFDM) successfully overcomes inter-symbol interference (ISI) in wireless medium. It is a parallel transmission scheme with multiple carriers. Where, a single data stream is transmitted over a number of lower rate subcarriers (SCs). One of the main reasons to use OFDM is to increase robustness against frequency-selective fading or narrowband interference in multipath environment. In this article, we present a better method for frame synchronization as compared to Schmidl-Cox [10] and Minn-Bhargava [5] methods. Frame synchronization is required as symbol time offset (STO) occurs due to channel-lag. The improvement in the variance and reduction in the plateau width of the timing metric has been discussed in detail.

Index Terms: Orthogonal frequency division multiplexing(OFDM), inter-symbol interference(ISI), subcarriers(SCs), frequency-selective fading, narrowband interference, symbol timing offset(STO) and timing metric.

I. INTRODUCTION

THE OFDM technique is used predominantly in 3G-4G wireless communication standards. The OFDM technique had been studied since late 1960s. After the IFFT/ FFT technique was introduced, the implementation of the OFDM became more convenient. This DFT technique for OFDM was introduced by Weinstein and Ebert in 1971 [12]. Earlier, in the year 1966, Chang [1] got the first patent over multichannel transmission of orthogonal signal. Present day, OFDM is also applied in wired systems like Asymmetric Digital Subscriber Line (ADSL) and high speed DSL. Another wired application of OFDM is PLC (PowerLine Communication). The wireless OFDM applications are numerous. This includes IEEE 802.11 a/g/n standards, IEEE 802.16 (Wi-Max) standards, 3GPP LTE, MIMO-OFDM, SC-FDMA and many more. Time synchronization of the frame means finding start of the OFDM symbol. For this, various algorithms have been presented till date. The maximum likelihood estimator was given by Moose[6]. Nogami and Nagashima [7] presented null symbol method. Van de Beek [3] explores the method of correlation of the cyclic prefix. Classen's method [2] describes the estimation of symbol timing and carrier frequency offset synchronization together. Classen uses trial and error method, which is very complex. The complexity of Classen method was reduced by Schmidl and Cox in their paper [10]. Further, Minn and Bhargava modifies Schmidl and Cox approach in [5]. In this article, we mainly address the timing synchronization issue. Section 2 describes how OFDM has evolved from multi-carrier modulation scheme. This section also stress upon the advantages of OFDM over filtered multi-tone technique. Section 3 classifies the types of timing methods and compares proposed algorithm with Schmidl-Cox and Minn-Bhargava methods. Finally, various simulation results are shown in section 4.

II. BASICS OF OFDM

Multiple carriers are used, instead of a single carrier in multi-carrier modulation scheme. This is done to overcome the frequency selectivity of the wideband channel and to achieve successful transmission for high data rate. Filtered multi-tone(FMT) modulation and Orthogonal Frequency Division Multiplexing(OFDM) are the two basic Multi-Carrier Modulation(MCM) scheme. Direct realization of FMT uses bank of filters, both at transmitter and receiver. OFDM deploys IDFT/DFT at transmitter and receiver.

A. Timing Offset Errors

It is clear that, OFDM technique is parallel transmission of data over Orthogonal subcarriers. It divides frequency selective channel into "N" flat fading channels. It avoidsISI(Inter-Symbol Interference) arising due to multi-path environment, by using concept of CP(Cyclic Prefix). As compared to basic Filtered Multi-Tone(FMT) scheme, OFDM uses channel bandwidth much more efficiently. All these advantages only holds when the ORTHOGONALITY" is maintained. Orthogonality can be lost due to Symbol Time Offset(STO) or Carrier Frequency Offset(CFO). STO arises due to mismatch between the starting points of transmitted and received OFDM symbol. CFO arises due instability in generation of carrier signal or due to doppler shift.

III. SYNCHRONIZATION METHODS

Timing synchronization methods are broadly classified as coarse timing and fine timing. Incoarse timing, repeated part of the symbol is used. Such parts are cyclic prefix, cyclic suffix or special PN-sequence. In such methods, receiver window correlates the received signal tofind repetition. The point of maximum correlation is said to be the start of frame.Through coarse synchronization, the estimation is not precise. So, in fine timing, an average of number of symbols is taken. Due to the averaging, optimal symbol timing can be derived. In this article, we will discuss Schimdl-Cox and Minn-Bhargava algorithms. With these algorithms, proposed method is compared.

A. Schmidl-Cox Method:

Fig. 3 shows the PN-sequence arrangement of Schmidl-Cox timing synchronization method [10]. In this method, even frequencies consists PN-sequence and odd frequencies are filled with zeros. The timing metric is given by:

$$
\begin{aligned}
M(d) &= \frac{|P(d)|^2}{|R(d)|^2} \\
where:& \\
P(d) &= \sum_{m=0}^{L-1} (r^*_{d+m} r_{d+m+L}) \\
R(d) &= \sum_{m=0}^{L-1} (r_{d+m+L})
\end{aligned}
$$

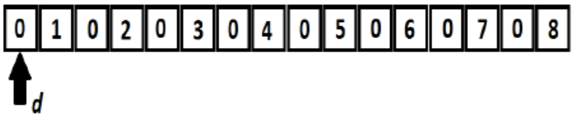

Fig.1. Schmidl-Cox PN-Sequence

Whehe d is the index of time. It corresponds to the first window sample. Total size of the window, for this method is L, shown in figure1.This algorithm leads to a formation of plateau consisting of samples equal to cyclic prefix. The plateau corresponds to variance in timing metric and increases the uncertainty in detection of start of frame. To combat occurrence of plateau, Schmidl-Cox suggested one averaging method. According to this method, first maximum amplitude-point of timing metric is found. Then, one point each at the left and right of this point with 90% amplitude is located. The start of frame is the average of these two points.

B. Minn and Bhargava:

Minn and Bhargava, in their paper [5] proposed another method whichcalculates R(d) with all the samples present in one symbol. As R(d) is half of the symbolenergy, the calculated energy is divided by 2. Averaging in this method isachieved as follows:

$$
\begin{aligned}
M(d) &= \frac{1}{N_g+1} \sum_{k=-N_g}^{0} M_f(d+k) \\
where:& \\
M_f(d+k) &= \frac{|P(d)|^2}{R_f^2(d)} \\
R_f(d) &= \frac{1}{2} \sum_{m=0}^{L-1} (r_{d+m+L})
\end{aligned}
$$

Where Ng is the guard interval and P(d) is same as in previous method. In the same paper [5], Minn proposed another method which exclude cyclic prefix and use PN-sequence of length one-fourth of the whole symbol, shown in fig 2. The metric is equated as follows:

$$
\begin{aligned}
M_2(d) &= \frac{|P_2(d)|^2}{R_2^2(d)} \\
P_2(d) &= \sum_{k=0}^{1} \sum_{m=0}^{L-1} (r^*_{d+2Lk+m} r_{d+2Lk+m+L}) \\
R_2(d) &= \sum_{k=0}^{1} \sum_{m=0}^{L-1} |r_{d+2Lk+m+L}|^2
\end{aligned}
$$

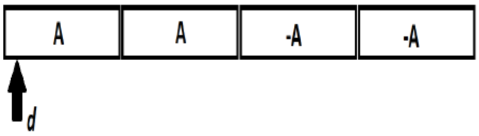

Fig. 2. Minn's PN-Sequence

C. Proposed Method:

The proposed method in this paper is the extension of the work, presented in [8]. We use the symmetry property of pn-sequence in this method. The pn-sequence shown in fig. 3 is obtained by taking IFFT of real-valued sequence and rearranging it. This real-valued sequence has zeros on the odd frequencies. In the figure, * denotes the conjugation. P(d) is the cross-correlation and R(d) is the auto-correlation of the PN-sequence:

$$
\begin{aligned}
P_3(d) &= \sum_{k=0}^{\frac{N}{2}-1} (r_{d-k} r_{d+k+1}) \\
R_3(d) &= \sum_{k=0}^{N-1} |(r_{d-\frac{N}{2}+k+1})|^2 \\
M_3(d) &= \frac{|P_3(d)|^2}{R_3^2(d)}
\end{aligned}
$$

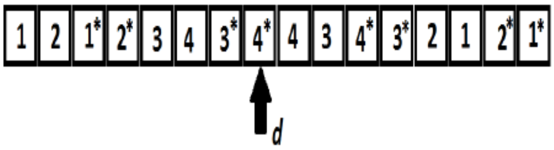

Fig. 3. Arrangement of PN-Sequence

The symmetry property helps us to attain only one mutual product for each member of the PN-sequence. Therefore, the peak of the metric occurs at correct sample, which is start of theframe. While, rest of the values tend to zero. This method correlate samples at position dwith d + 1, then d - 1 with d + 2 and so on. The correlation operation begins when thesliding window reaches the arrow shown in the figure 5. The metric proposed here, has theleast variance as compared to Minn-Bhargava or Schmidl-Cox methods. The plateau regionis non-existent. The peak of metric has one and only one sample, which is the startingpoint of the frame. Statistical details and comparisons of all the three algorithms arediscussed in next section.

IV. RESULTS & SIMULATION

For the simulation purpose, standard 802.11a is used. In this standard, QPSK technique provides12 Mbps bit rate. 4 microsec is the symbol interval and the sub-carrier spacing is 0.3125 MHz for FFT size equal of 64, which is calculated as:

$$
\frac{20MHz}{64} = 0.3125MHz
$$

Occupied bandwidth is 16.6 MHz as 52 subcarriers are used. Out of 52, 4 sub carriers are used for pilot-carriers and rest 48 for data carriers.

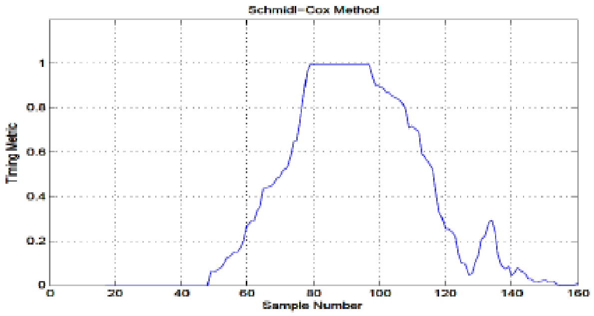

Fig. 4. Metric-Plot of Schmidl-Cox Method

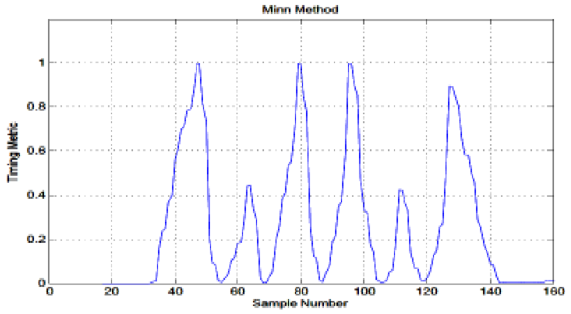

Fig. 5. Metric-Plot of Minn-Bhargava Method

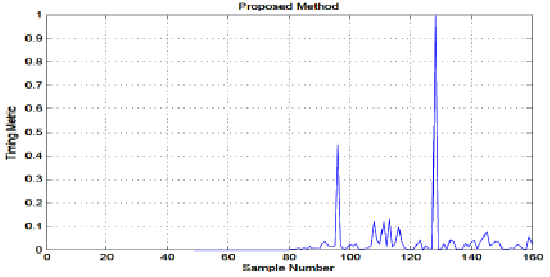

Fig. 6. Metric-Plot of Proposed Method

The graphs shown in fig. 6, 7 & 8 are the simulated timing-metric for respective algorithms. Here, SNR is considered to be infinite. The plateau-width present in Schmidl-Cox metric is equal to cyclic-prefix, which consists 16 samples (between sample 80 to 96). Start of symbol is from sample 97. Minn's method also shows starting sample at 97. But, there exists other peaks with amplitude comparable to the peak at sample number 97. In the metric plot of the proposed method, at sample number 128 maximum peak occurs. This peak has zero plateau and no other peak exist at any other sample which can be confused by peak at sample 128. From the graphs, it is clear that the peak of the pulse should contain starting sample. Therefore, the peak-width should be minimum and must contain least number of samples. Ideally, an impulse must exist only at that sample from where frame is starting. On the other hand, the maximum width of the pulse is when the amplitude of metric is minimum, i.e at the bottom. The proposed method is found to be better and advantageous as the peak is singleand sharper as compared Minn-Bhargavamethod.

V. CONCLUSION

In this article, standard IEEE 802.11a is studied under varying conditions of different algorithms. The proposed method is found to be better and advantageous as the peak is single and sharper as compared Minn-Bhargava method. Also, there is no plateau formation. Whereas, in Schmidl-Cox method, a plateau of the length of cyclic-prefix exist. The proposed method may found very consistent under different values of SNR.

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