

Symbol Timing Synchronization for ISDB-T System in Multipath Fading Channel

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Abstract— This paper proposes a symbol timing synchronization method for Integrated Services Digital Broadcasting Terrestrial (ISDB-T) system. In order to estimate symbol timing, we employ correlation based synchronization in time domain by exploiting periodical pattern, that is introduced by Cyclic Prefix of ISDB-T OFDM frame structure. This periodical pattern induces higher correlation result in the beginning of each symbol, which gives us the information about the start of symbol. To increase the performance of system in Multipath Fading environment, we propose DFT window shift method. The correlation method just produces rough estimation of the start of symbol. The estimation result still cannot avoid Inter Symbol Interference. In order to avoid interference, we proposed DFT window shift. Simulation results shows that the proposed synchronizer can improve the performance of system in multipath fading channel. The proposed design has been verified in Rayleigh channel.

Keywords— Symbol Timing Synchronization, OFDM, ISDB-T, DFT Window Shift, Multipath Fading

I. INTRODUCTION

ISDB-T (Integrated Services Digital Broadcasting-Terrestrial)[1] is the advanced international standard on DTTB (Digital Terrestrial Television Broadcasting) format originally developed in Japan. DTTB services using ISDB-T started in Japan in December 2003 and in Brazil in December 2007. The number of the country which has adopted its standard is gradually increasing with the recognition of its technological advantage. ISDB-T has been adopted by almost all country in South America in 2009, such as Argentina, Peru, Chile, and Venezuela.

One of the most technical advantage of ISDB-T is the OFDM segmented transmission that enables fixed, mobile, and portable transmission all in one channel. As a comparison, DVB-T and ATSC require another channel for portable reception service, on the other hand, ISDB-T enables fixed/mobile/portable service in same channel by one transmitter. It leads not only saving the frequency resource but also saving transmitter cost. The transmitted signals are divided into 13 segments with a bandwidth of 5.57 MHz bandwidth. It enables us to broadcast for various different purposes because we can change the parameter in each segment. Using 12 of the 13 segments enables High-Definition Television (HDTV) services and using 4 segments enables Standard Definition Television(SDTV) services.

Moreover, one of the 13 segments is specially designed for one-segment reception, enabling ISDB-T transmission to mobile terminals by using only this segment.

In OFDM(Orthogonal Frequency Division Multiplexing) receiver, there is a problem to determine the starting point of OFDM symbols (symbol timing synchronization) because it doesn't know exactly the arrival time of OFDM symbol. The symbol timing error can disturb the amplitude as well as the phase of the received signal, but also introduce ISI(Inter Symbol Interference)[5]. The demodulation of signal that contains the time offset will dramatically increase bit error rate.

This paper proposes robust symbol synchronization timing for ISDB-T system in Multipath Fading Channel. Since ISDB-T system has no preamble data, we use Cyclic Prefix for time-and-frequency synchronization. Two stages synchronization are employed to increase system performance. In time domain, synchronization is performed by exploiting the CP of OFDM frame structure. Firstly, We employ synchronization based on autocorrelation method [2][3]. Secondly, We employ DFT window shift to avoid ISI. The synchronizer design will be verified in multipath Rayleigh fading channel model.

II. SYNCHRONIZATION PROBLEM IN MULTIPATH FADING CHANNEL

ISDB-T system was designed based on the OFDM. One of the main advantage of OFDM is the robustness over frequency selective fading channel because it divides the entire frequency band into a number of parallel subcarriers, each of which experiences flat channel fading. It is beneficial for terrestrial system e.g. ISDB-T which is transmitted through multipath channel and suffered performance degradation due to frequency selective fading. OFDM systems also have efficient spectrum utilization due to the overlapping spectra of subcarrier signals. It is also beneficial for ISDB-T in order to use available spectrum efficiently. However, this is only true when the orthogonality among subcarriers is preserved. If it isn't preserved, system performance will be degraded due to Inter Symbol Interference (ISI) and Inter Carrier Interference (ICI). In the following, synchronization errors and their effects on the received frequency-domain signals will be explained briefly.

An OFDM baseband symbol is generated by modulating N complex data using the Inverse Discrete Fourier Transform (IDFT) on N subcarriers. The subcarrier spacing is $1/T_u$, where T_u is duration of N time domain samples. In order to avoid ISI, Cyclic Prefix is inserted at the beginning of each symbol which makes every OFDM symbol has $N + N_g$ samples. The n -th time domain sample of the i -th transmitted symbol can be expressed as:

$$x(t) = x_{i,n} = \frac{1}{N} \sum_{k=-N/2+1}^{N/2} X_{i,k} e^{j2\pi nk/N}$$

$$n = -N_g, \dots, N-1 \quad (1)$$

where $x(t)$ and $X_{i,k}$ are time-domain transmitted signal and frequency-domain transmitted signal in i -th symbol.

The transmitted signal, $x(t)$, will be transmitted through multipath fading channel, as shown in (2)

$$h(t, \tau) = \sum_r h_r(t) \delta(\tau - \tau_r(t)) \quad (2)$$

where $h_r(t)$, $\tau_r(t)$, and τ are gain of the r -path, delay of r -path, and time delay variable, respectively.

By convolving the transmitted signal with the channel impulse response and adding the channel noise, $v(t)$, the received signal is given by

$$z(\tau) = \sum_r h_r(t) x(\tau - \tau_r(t)) + v(t) \quad (3)$$

In the next subsection, we will explain briefly the effect of Symbol Timing Offset to received signal.

A. Effect of Symbol Timing Offset

Before processing DFT, receiver needs to determine the start of symbol. This information will be utilized by receiver to locate the DFT window after removing the Guard Interval. The falseness in determining the start of DFT window position introduces phase shift and ISI in frequency domain received signal[5]. Assume the maximum delay spread is shorter than Guard Interval length, there are three possibilities of DFT Window position falseness, as shown in Figure 1[5]. When DFT window is earlier by T_d , but it is not contaminated by delayed previous symbol, the transform received signal is free from ISI. It is called the safe DFT Window. In this case, only additional phase shift is introduced in the transform signal, as shown in (4).

$$Z_k = X_k H_k e^{-j2\pi T_d k / (NT_s)} + V_k \quad (4)$$

Where Z_k , X_k , H_k and V_k are the received frequency-domain signal, transmitted frequency-domain signal, channel response, and noise signal of the k -th subcarrier, respectively. T_d is the difference between the detected symbol start and the actual symbol start and T_s is the duration of one sample.

On the other hand, there are two possibilities when received signal can be interfered by another symbol. First possibility is when the DFT window leads by large degree and it is interfered by delayed previous symbol. The second possibility is when the DFT window lags, so it interferes with the next symbol. Both case introduce ISI and distortion to magnitude and phase of Z_k , as shown in (5).

$$Z_k = X_k H_k \frac{N - |T_d|/T_s}{N} e^{-j2\pi T_d k / (NT_s)} + ISI + V_k \quad (5)$$

There are three terms in (5). The first term is the part of received frequency-domain signals that are free from ISI. The second term is the part of received frequency domain signals which are interfered by ISI and the latter is the channel noise component. Equation (5) shows that there is slight decrease in the amplitude of the first term besides the phase shift. It happens because there are $|T_d|/T_s$ samples that suffer interference from another symbol (second term). Therefore, only $N - |T_d|/T_s$ samples are from desired symbol and free from ISI.

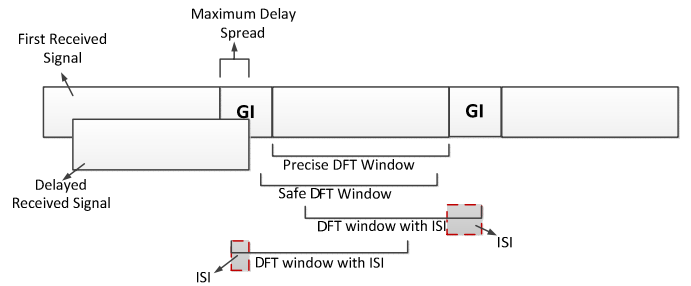


Figure 1. Possibility of DFT Window Location

III. SYNCHRONIZATION BY AUTOCORRELATION

Coarse estimation of Symbol Timing Synchronization can be done based autocorrelation method[2][3]. It exploits periodic part in OFDM frame structure from received signal, i.e. Cyclic prefix. The appearance of Cyclic Prefix yields a correlation between some pairs of samples that are space N samples apart (N is DFT window size). It makes received signal, because of its probabilistic structure, contains information about time offset θ . Equation (6) shows the estimation based on Autocorrelation Method.

$$\Lambda(\theta) = |re\{\gamma(m)\}| + |im\{\gamma(m)\}| \quad (6)$$

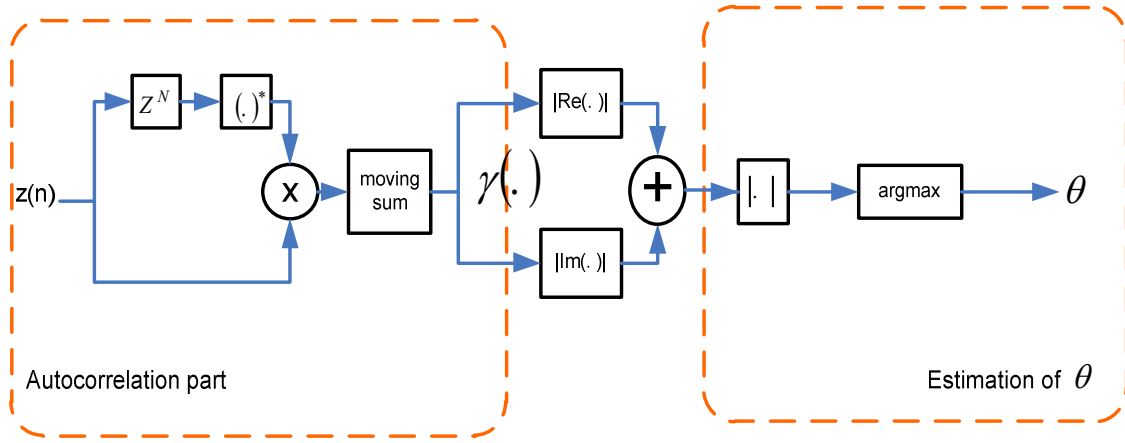


Figure 2. Autocorrelation Block Diagram

where

$$\gamma(m) = \sum_{k=m}^{m+M-1} z(n) z^*(n+N) \quad (7)$$

m , M , N , and $z(n)$ are correlation sample index, Cyclic Prefix ratio * number of subcarrier, number of subcarrier, and received signal in time instant n , respectively. $\gamma(m)$ is the result of consecutive sample correlation between pairs of samples that N samples apart. The estimation of the start of symbol, θ , becomes

$$\hat{\theta}_{ML} = \arg \max \{ \Lambda(\theta) \} \quad (8)$$

The terms, $\hat{\theta}_{ML}$, is the time instants when the maximum value of $\Lambda(\theta)$ is detected. The autocorrelation result, $\gamma(m)$, results on the maximum value at the start of every symbol, as shown in Figure 3.

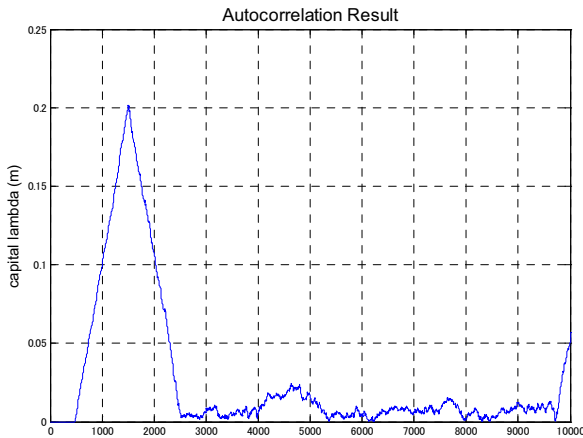


Figure 3. Autocorrelation Results

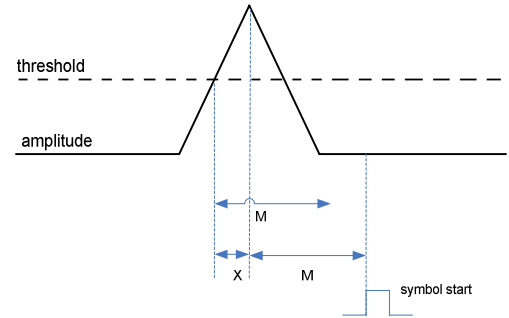


Figure 4. Method of Finding Position of peak and start of symbol

Correlation peaks are the result of correlation between Cyclic Prefix and its duplicate in last part of every symbol. In order to detect the start of symbol, we exploit peak value of the correlation result, as shown in Figure 4. When the amplitude is higher than threshold, a symbol start search is started. It will detect the maximum value for next M sample range (M is number of sample in Cyclic Prefix). After finding maximum peak in position, X , we can estimate the symbol start as the next M sample from detected peak position, X .

IV. DFT WINDOW SHIFT

In order to improve the performance of Symbol Timing in Multipath fading channel, we introduce DFT Window Shift. Based on the symbol timing estimation results by Autocorrelation based methods, there are still exist small timing error, as shown in Figure 5.

Mean Time Estimation Error means the average shift of symbol start estimation from the actual symbol start. From Figure 5, we can conclude that the DFT window position lags compared to actual DFT window position. We can conclude that by using autocorrelation based symbol timing estimation method, the received signals still suffer performance degradation caused by ISI.

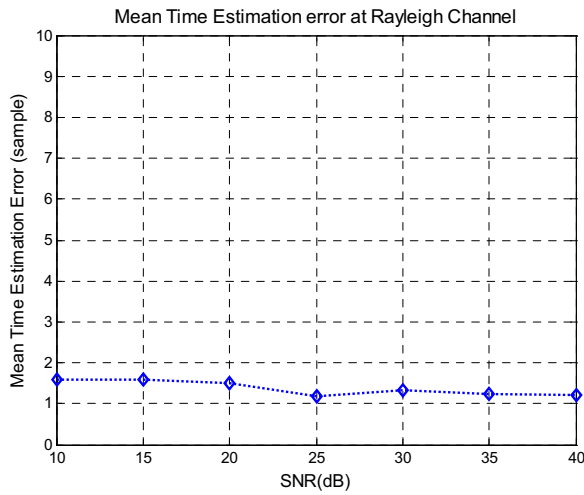


Figure 5. Mean Symbol Timing Estimation Error

In order to avoid ISI, we propose the DFT window shifted to locate the DFT window position in the safe position as discussed in section II. Since, the value of mean timing estimation error always positive, we propose the backward shift DFT window position, as shown in Figure. 6.

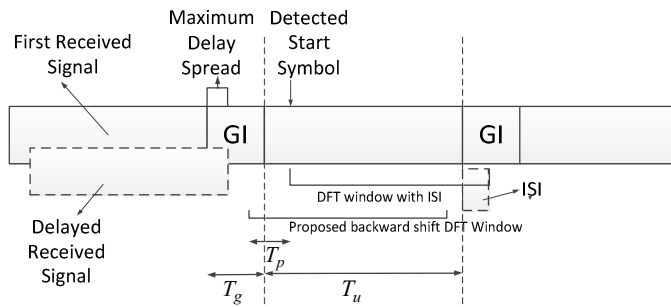


Figure 6. Proposed DFT Window Shift

V. SIMULATION MODEL

A. Simulation System Parameter

In this simulation, We use mode 3 of ISDB-T transmission mode. ISDB-T introduces three transmission mode according to the space between carrier frequencies width. Mode 3 introduces 1 KHz subcarrier spacing ($\sim 0.99206\text{KHz}$) width and number of carrier per symbol is 5617 carrier. The DFT size is 8192 and we use guard interval ratio = $1/8$ ($1/8 \times 8192 = 1024$). For every SNR value, we simulate 1 frame ISDB-T signal in 50 iteration. Complete simulation system parameter is shown in Table 1.

TABLE 1. SIMULATION SYSTEM PARAMETER

Mode	Mode 3
Spacing between carrier frequencies	0.99206 KHz
Number of carrier per symbol	5617 carrier
DFT Size	8192
Guard Interval ratio	1/8
Modulation	QAM-64

Convolutional Code	$3/4$
Number of Iteration	100
Number of frame	1(3973376 [bit])
Effective Symbol length	1.008 [ms]

B. Multipath Fading Channel Model

In the simulation, we employ multipath fading channel model with Rayleigh distribution. For the multipath channel, We employ GSM Typical area model[4]. The average relative power and relative time characteristic of GSM Typical area channel model is shown in Table 2.

TABLE 2. GSM TUX SETTING

Tap Number	Relative time (μs)	Average relative power (dB)
1	0.0	-3.0
2	0.2	0.0
3	0.5	-2.0
4	1.6	-6.0
5	2.3	-8.0
6	5.0	-10.0

For the error synchronization, We make the model of synchronization error according to (9)

$$r(n) = s(n - \theta) \quad (9)$$

$r(n)$ and $s(n - \theta)$ are received signal in time instants n , transmitted signal in time instant n delayed by θ sample, respectively. Complete channel model parameter is shown in Table 3.

TABLE 3. Channel Model Parameter

Multipath Model	Channel	GSM Typical urban area model (6 taps)
Fading		Rayleigh block fading
Time offset (θ)		1500 (samples)

VI. SIMULATION RESULTS

In this section, We present simulation results for synchronization system performance in receiving HDTV contents in Multipath Fading environment. In this simulation we will simulate the performance of proposed method, DFT window shift, in improving the performance of symbol timing synchronization.

Before simulating BER performance of proposed method, we need to look for the appropriate backward shift value for our system. As we know, since we need to put the DFT window starting from any points inside Guard Interval, therefore we will move the DFT window backward from the previous detected position. In order to know how many shift that we need to get the the best performance, we need to consider about the value of Cyclic Prefix and maximum delay

spread. From system simulation parameter (Table 1) and channel model delay characteristic (Table 3), we know that the cyclic prefix size is 1024 and maximum delay spread is $5\mu\text{s}$ (~ 41 time sample). ISI can be removed if $T_p = T_g/2$ is set for all transmission mode combinations in ISDB-T, except for mode 1 with GI mode 1/32 (GI length = $7.875\mu\text{s}$). In this simulation, since $T_g = 1024$, then $T_p = 512$ sample. As a comparison, we also plot the BER performance of system in perfect synchronization mode, which means the mode where the time offset and CFO can be perfectly detected and recovered

Figure 7 shows that the performance of autocorrelation based Synchronization is not good. We are not surprised with this results since that method was basically proposed for AWGN channel [2]. By using proposed DFT window shift we get much better performance in multipath fading channel. We can see that the performance between proposed DFT window shift method with the perfect synchronization mode is not much different.

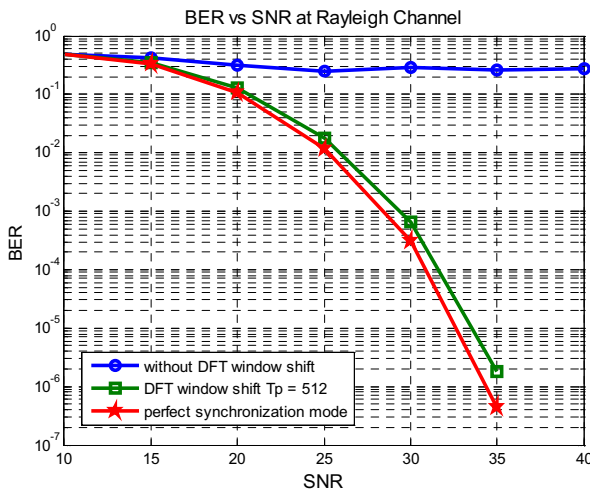


Figure 7. Performance of DFT Window Shift

VII. CONCLUSIONS

In this paper, we propose the symbol timing synchronization method for ISDB-T system for HDTV contents transmission in Multipath Fading Channel. Synchronization based on autocorrelation have been reviewed. The effect of a DFT window position error has also been reviewed. Based, on this knowledge, we have proposed DFT window shift to increase the performance of autocorrelation based synchronization in Multipath fading channel. According to simulation result, proposed synchronizer, backward DFT window shift method, can improve performance of symbol timing synchronization.

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