An Improved Residual Frequency Synchronization Method for Wireless Communication System

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Abstract**—** This paper proposes an improved residual frequency offset (RFO) estimation method in the cyclic prefix orthogonal frequency division multiplexing (CP-OFDM) based wireless communication system. The proposed method is based on the sidelink primary synchronization signal (S-PSS) sequences inserted into the sidelink synchronization signal/physical sidelink broadcast channel (S-SS/PSBCH) block used to estimate the synchronization error in the 5G NR sidelink system. The proposed RFO estimation method has a more improved estimation performance than the conventional method. The computer simulation is used to assess the performance of the proposed scheme and to make comparison with the conventional scheme.

Keywords— CP-OFDM; synchronization; residual frequency offset

I. Introduction

The 5G new radio (NR) communication system has developed from the technologies used in the existing 4G long term evolution (LTE). Important feature of 5G compared to previous generations is the support of flexible frame structures by multiple numerologies. The numerologies and physical layer parameters are defined by its subcarrier spacing [1]-[3]. The waveform of the 5G NR communication system has adopted a cyclic prefix orthogonal frequency division multiplexing (CP-OFDM) modulation scheme. The CP-OFDM technology has been applied to communication systems that require high-speed data transmission and reception in the frequency selective fading channel. In CP-OFDM based communication systems, frequency selective wideband channel is divided into frequency flat narrowband sub-channels which have an orthogonal to each other. In other words, since the whole channel bandwidth is split into several sub-channels, the channel frequency response over each separated subcarriers becomes non-frequency selective fading channel [4]. This characteristic enables for CP-OFDM based communication systems supporting high data rates when symbol durations much longer than the frequency response of the channel. However, the CP-OFDM based communication systems for high-speed data transmission has certain disadvantage. The primary problem of CP-OFDM based communication systems is sensitive to synchronization error which may lead to severe degradation in performance of each systems. To solve this problem, various methods for estimating and compensating synchronization errors that cause inter symbol interference (ISI) and inter carrier interference (ICI) have been studied [5]-[8]. This synchronization errors can be divided into carrier frequency offset (CFO) and symbol timing offse (STO). In general, CFO can be subdivided into fractional frequency offset (FFO), integer frequency offset (IFO), residual frequency offset (RFO), and sampling frequency offset (SFO) [9]. STO and FFO are estimated and compensated in the pre-FFT step, and IFO, RFO, and SFO are estimated and compensated in the post-FFT step. In mobile communication systems such as CP-OFDM based 4G and 5G, a physical cell identity estimation procedure is additionally included in the post-FFT step [1]. RFO remains subtle after FFO estimation and compensation procedures in the pre-FFT step. RFO tracking is a very important part of CP-OFDM based communication systems because RFO rotates the phase of the received modulated signal, causing a fatal problem that makes it impossible to accurately demodulate the signal. In particular, in a communication system having dual mobility between a transmitter and a receiver, such as V2X communication, synchronization error tracking procedures are very important. For this reason, this paper deals with an improved RFO estimation method for 5G NR sidelink system. By taking advantage of the synchronization signals property, RFO can be estimated using the correlation function based on sidelink primary synchronization signal (S-PSS).

The outline of this paper is as follows. Chapter II presents the system model in the 5G NR sidelink system using the CP-OFDM waveform. In chapter III, an improved RFO estimation method is proposed using SPSS sequence in the 5G NR sidelink system. Chapter IV presents simulation results proving the effectiveness of the proposed method and conclusion is given in chapter V.

II. System Description

A. S-PSS sequence

5G NR sidelink system uses a synchronization signal /physical sidelink broadcast channel (SS/PSBCH) block to estimate the synchronization errors. At here, the S-PSS sequence is inserted into the first and second CP-OFDM symbols of the SS/PSBCH block. The S-PSS sequence is generated by

$$d_{S-PSS}(k) = 1 - 2x(m), \quad m = (n + 22 + 43N_{ID,2}^{SL}) \bmod 127 \quad (1)$$

where

$$\begin{aligned} &x(i+7) = (x(i+4) + x(i)) \bmod 2 \\ &[x(6)\ x(5)\ x(4)\ x(3)\ x(2)\ x(1) x(0)] = [1\ 1\ 1\ 0\ 1\ 1\ 0] \end{aligned} \quad (2)$$

where $N_{ID,2}^{SL} \in \{0,1\}$, S-PSS sequence of the SS/PSBCH block is consisted of 127 subcarriers from 1 to 128 [1].

B. Signal Model

In this section, it is considered that a OFDM system consists of N -point FFT size and N_g CP size. In the receiver of 5G NR sidelink system, FFT is performed after the STO is perfectly compensated and CP is removed. At this time, the $l-$th received signal in the frequency domain is expressed as follows

$$R_l(k) = H_l(k)S_l(k)e^{j2\pi(\delta_r + k\delta_s)(lN_c + N_g)/N} + I_l(k) + Z_l(k) \quad (3)$$

where δ_r is RFO, δ_s is SFO, $H_l(k)$ is channel's frequency response, $S_l(k)$ is the transmitted signal, $I_l(k)$ is the ICI term caused by the RFO δ_r and SFO δ_s , and $Z_l(k)$ is the complex additive white Gaussian noise (AWGN). In this paper, it is assumed that the first S-PSS sequence is located at the l -th CP-OFDM symbol, and the second S-PSS symbol is located at the $l+1$-th CP-OFDM symbol.

III. Proposed Method

SFO and RFO are caused by the difference in oscillator performance. SFO which is a fraction of the subcarrier spacing can be expressed as $\delta_s / T_s = (\delta_r \Delta_f / f_c) f_s$. $1/T_s$ is sampling frequency, Δ_f means the subcarrier spacing, and f_c is the center frequency. From this observation, RFO and SFO are coupled with each other $\delta_s \approx -(\Delta_f / f_c)\delta_r$. For example, assuming that the center frequency f_c is 6GHz and sampling frequency Δ_f is 15KHz in the 5G NR sidelink system, $\Delta_f / f_c = 2.5 \cdot 10^{-6}$. Considering this case, this chapter assumes that there is no SFO and only estimate RFO. This chapter deals with the RFO estimation method using the SPSS sequence in the 5G NR sidelink system. The first step, in order to relatively alleviate the characteristics of the frequency selective fading channel, a multiplication operation is performed on the subcarriers of the l -th symbol with a difference of a D_t distance. The $l+1$ -th symbol is also performed in the same way. The corresponding multiplication operation can be expressed as

$$M_i(k) = \sum_{i=0}^{1} R_{l+i}(k) R_{l+i}(k + D_t) \quad (4)$$

As a second step for estimating the RFO, a correlation operation is performed between the multiplication operation value of the l -th symbol and the multiplication operation value of the $l+1$ -th symbol. It can be expressed as

$$C(k) = \sum_{k=0}^{P} M_1^*(k) M_2(k) \quad (5)$$

where $P = K - D_t$ K means the size of the SPSS sequence. To estimate the RFO, each of the two consecutive S-PSS sequences are subjected to a correlation operation . From the (4) and (5), it can be estimated the RFO. The proposed RFO estimator has the following equation

$$\delta_r = \frac{1}{2} \frac{N}{2\pi N_c} \sum_{k=0}^{P} \arg\{C(k)\} \quad (6)$$

where $\arg\{C(k)\}$ is the angle of the phase rotated $C(k)$.

IV. Simulation Result

To demonstrate the performance of the proposed RFO estimation method in the 5G NR sidelink system, this chapter shown the simulation result by computer simulation. The parameters of 5G NR sidelink system used for computer simulation are as follows. The subcarrier spacing Δ_f is used 15KHz, center frequency f_c is considered 6GHz, and sampling frequency is used 30.72MHz. The FFT length is considered 2048, the normal CP is used and the length of this CP is used 144. Length of the SPSS sequence $d_{S-PSS}(k)$ is 127 and the modulation of transmission data is used quadrature phase shift keying (QPSK). The value of SFO δ_s is generated according to $\delta_s \approx -(\Delta_f / f_c)\delta_r$. To perform the computer simulation, multipath fading channel is considered. In this case, the channel model is considered the tapped delay line-A (TDL-A) of 3GPP TR 38.900 and TR 38.901. The TDL-A model for simplified simulations can be used for the frequency range 0.5GHz ~ 100GHz with a maximum bandwidth of 2 GHz [10][11]. In [10][11], parameters of the TDL-A channel model is specified by normalized delay spread (DS) = [0 0.3819 0.4025 0.5868 0.4610 0.5375 0.6708 0.5750 0.7618 1.5375 1.8978 2.2242 2.1718 2.4942 2.5119 3.0582 4.0810 4.4579 4.5695 4.7966 5.0066 5.3043 9.6586] (in [ns]) and power = [-13.4 0 -2.2 -4 -6 -8.2 -9.9 -10.5 -7.5 -15.9 -6.6 -16.7 -12.4 -15.2 -10.8 -11.3 -12.7 -16.2 -18.3 -18.9 -16.6 -19.9 -29.7] (in [dB]). The scaling of delays can be acquired according to $\tau_{n,\text{model}} \times DS_{\text{desired}}$. $\tau_{n,\text{model}}$ is the normalized delay value in the TDL-A channel model, and DS_{desired} is the wanted DS (in [ns]).

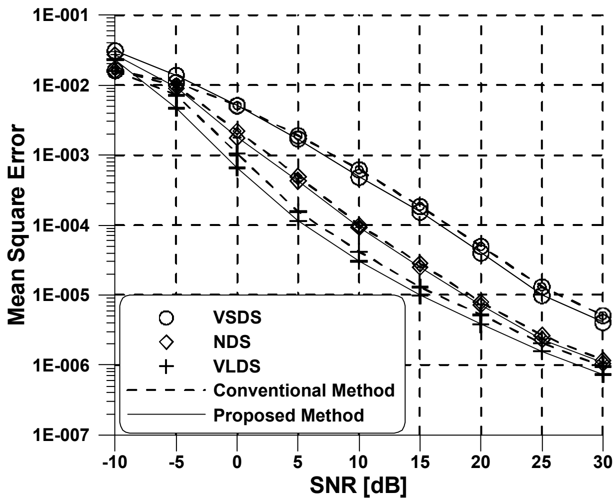

Fig. 1. MSE performance of the conventional and proposed RFO method

To verify the performance of the proposed RFO estimation method, mean square error (MSE) performance comparison was performed and then, the RFO $\delta_r = 0.02$ that normalized by subcarrier spacing is considered in the computer simulation. Fig. 1 shows the MSE performance of the proposed RFO estimation method versus signal to noise ratio (SNR) value from -10dB to 30dB. From the simulation results, we can see that the performance of the proposed RFO estimator is improved in the frequency selective fading channel.

V. CONCLUSION

To fully obtain the advantageous features of CP-OFDM in the 5G NR sidelink system, it is very important to maintain the frequency synchronization between the transmitter and the receiver. To solve the synchronization problem, this paper proposed an efficient RFO estimation scheme in the CP-OFDM based 5G NR sidelink system with S-PSS sequences. The proposed RFO estimation method is designed using the characteristics of the S-PSS sequence transmitted by inserting it into consecutive CP-OFDM symbols in the SS/PSBCH block of the 5G sidelink system. In order to verify the performance of the proposed scheme, computer simulation is used. From the computer simulation result, it was shown that the proposed method has efficient performance compared to the conventional method. However, in order to apply the proposed method in a mobile network environment, it is necessary to confirm more performance by adding various experimental conditions and to improve the performance of RFO estimator.

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