Residual Frequency offset Estimation Scheme for 5G NR System

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***Abstract*—The primary synchronization signal (PSS) and secondary synchronization signal (SSS) transmitted in the 5G are used to perform a synchronization procedure. This paper proposes an effective residual frequency offset (RFO) estimation method in a 5G new radio (NR) system. The proposed RFO estimation method applies two branches correlation using PSS and SSS sequence. This paper shows via the simulation results that the inherent property of the PSS and SSS signals is exploited for a robust RFO estimation at various delay spread of wireless environments. It is demonstrated that the proposed RFO estimation scheme is efficient for the 5G NR system.**

Keywords—5G, synchronization procedure, residual frequency offset, PSS, SSS

I. INTRODUCTION (*HEADING 1*)

The fifth generation (5G) communication flows in the direction of evolving from the technologies used in the fourth generation (4G), rather than applying the new roll-up technology. The main difference between 4G and 5G system is that the frame structure is consisted of a flexible part to consider various service scenarios. Important feature of 5G new radio (NR) compared to 4G system is the support of flexible frame structures by subcarrier spacing. The waveform has adopted a cyclic prefix orthogonal frequency division multiplexing (CP-OFDM) and discrete Fourier transform spread OFDM (DFT-S-OFDM) modulation scheme in the third generation partnership project (3GPP) 5G NR [1]. The CP-OFDM has been used in various wireless communications system thanks to use high-speed data transmission in frequency selective fading channel. However, there are main demerit in the CP-OFDM based systems. It has susceptible to synchronization error which can lead to performance degradation of each system. As a result, estimation and compensation of time and frequency offset have become a major concern in OFDM-based wireless communication systems. To solve these problems, synchronization procedure is carried out in initial cell search of 5G NR system and the next generation node B (gNB) periodically transmits to user equipment (UE)s synchronization signals which is called as primary synchronization signal (PSS) and secondary synchronization signal (SSS) [2]. Synchronization error estimation schemes have been studied in many papers, and this synchronization error tracking can be divided into pre-fast Fourier transform (FFT) and post-FFT [3]. Generally, symbol timing offset (STO) and fractional frequency offset (FFO) estimation are performed in pre-FFT step by using the CP of the OFDM symbol and PSS sequence [4]. When FFO and STO are compensated and CP is removed, the received samples in time domain are transformed to the frequency domain by using the FFT processing. Integer frequency offset (IFO) and cell identity made up of sector cell identity and group cell identity detection are performed by using PSS and SSS in post-FFT step [5][6]. However, a residual frequency offset (RFO) remains after initial FFO estimation process [7]. RFO tends to occur due to the Doppler shift and inaccurate estimation. Uncompensated RFO will introduce phase rotations of received signal, so this RFO tracking is very crucial part of CP-OFDM based 5G NR system. For this reason, 5G NR system requires an accurate RFO estimation procedure in frequency domain. This paper introduces efficient RFO estimation method for 5G NR system. By taking advantage of the synchronization signals property, RFO can be estimated using the two steps correlation by PSS and SSS.

The rest of this paper is structured as follows. Next chapter presents the system model of 5G NR and the proposed RFO estimation scheme is presented in section III. Chapter IV presents simulation results and conclusion is given in chapter V.

II. SYSTEM MODEL

This paper considers a CP-OFDM based 5G system which is consisted of N -point IFFT size. After taking IFFT in the $l-$th symbol period, CP-OFDM symbol $X_l(k)$ is transformed to time domain signal and inserted CP with a length of N_{CP}. This signal in time domain is expressed as

$$x_l(n) = \sum_{k=0}^{N-1} X_l(k) e^{j2\pi kn/N} \quad (1)$$

where $n = -N_{CP}, -N_{CP}+1, ..., N-1$, $X_l(k)$ is the transmission signal with a symbol duration of $T = (N + N_{CP})T_s$. T_s is sampling time and the k means the index of sub-carrier. The transmitted signal from the transmitter arrives to the receiver after passing through a multipath channel with AWGN. And then, the received signal is converted to baseband and sampled with T_S period. This paper considers the situation that RFO remaining after initial CFO estimation process in pre-FFT. When the STO is accurately compensated and the CP is removed in the time domain, $l-$th received signal after FFT processor is shown by

$$\begin{aligned} Y_l(k) &= \Lambda(k) H_l(k) X_l(k) e^{j2\pi(\delta_r + k\delta_s)(lN_u + N_{CP})/N} \\ &+ I_l(k) + Z_l(k) \end{aligned} \tag{2}$$

where
$\Lambda(k) = (\sin(\pi(\delta_r + k\delta_s))) / (N \sin(\pi(\delta_r + k\delta_s)/N)) \approx 1$,
$X_l(k)$ is the symbol transmitted over the $k-$th subcarrier of $l-$th CP-OFDM symbol, δ_r is the RFO, δ_s is the sampling frequency offset (SFO). $H_l(k)$ denotes the channel's frequency response over the $l-$th period, $I_l(k)$ means the inter-carrier interference (ICI) term and $Z_l(k)$ represents a complex additive white Gaussian noise (AWGN). To consider that δ_r and δ_s are related to $\delta_s = -(\Delta f / f_c)\delta_r$, the δ_s is negligible for typical values of δ_r.

III. Proposed Scheme

This section presents an efficient RFO estimation scheme using characteristics of the synchronization signals in the 5G NR system. To estimate the RFO, this paper adopts two branches correlation, which are used to eliminate the effect of channel and dedicated synchronization signals, respectively. The distance between PSS and SSS symbol is $D = 2$ in the synchronization signal block [1]. Assuming $H_l(k) \approx H_{l+D}(k)$, the first correlation operation is written by

$$R_1(k) = Y_l^*(k) Y_{l+D}(k) \tag{3}$$

where (3) can be rewritten by

$$\begin{aligned} R_1(k) &= |H_l(k)|^2 X_l^*(k) X_{l+D}(k) e^{j2\pi\delta_r DN_u/N} \\ &+ \overline{I}_l(k) + \overline{Z}_l(k) \end{aligned} \tag{4}$$

where $\overline{I}_l(k)$ and $\overline{Z}_l(k)$ are expressed as

$$\begin{aligned} \overline{I}_l(k) &= H_l^*(k) X_l^*(k) I_{l+D}(k) e^{-j2\pi(\delta_r + k\delta_s)(lN_u + N_{CP})/N} \\ &+ H_{l+D}(k) X_{l+D}(k) I_l^*(k) e^{j2\pi(\delta_r + k\delta_s)((l+D)N_u + N_{CP})/N} \\ &+ I_{l+D}(k) I_l^*(k) \end{aligned} \tag{5}$$

and

$$\begin{aligned} \overline{Z}_l(k) &= H_l^*(k) X_l^*(k) Z_{l+D}(k) e^{-j2\pi(\delta_r + k\delta_s)(lN_u + N_{CP})/N} \\ &+ H_{l+D}(k) X_{l+D}(k) Z_l^*(k) e^{j2\pi(\delta_r + k\delta_s)((l+D)N_u + N_{CP})/N} \\ &+ I_{l+D}(k) Z_l^*(k) + I_l^*(k) Z_{l+D}(k) + Z_l^*(k) Z_{l+D}(k) \end{aligned} \tag{6}$$

TABLE I. Scaling parameters for TDL-A channel model

Model	Delay spread
Very short delay spread	10 ns
Nominal delay spread	100 ns
Very long delay spread	1000 ns

The second correlation operation is used to remove the dedicated received signals. For this purpose, $R_2(k)$ is constructed by

$$R_2(k) = X_l^*(k) X_{l+D}(k) \tag{7}$$

where $X_l(k) = d_{PSS}(k)$ and $X_{l+D}(k) = d_{SSS}(k)$ are PSS sequence and SSS sequence, respectively. Using two branches correlation operator of (3) and (7), the RFO $\hat{\delta}_r$ estimation can be calculated by

$$\hat{\delta}_r = \frac{1}{K} \frac{N}{2\pi D N_u} \sum_{k=0}^{K} \arg\{C(k)\} \tag{8}$$

where $D = 2$, K is the length of PSS symbol and SSS symbol, $\arg\{x\}$ denotes the angle of x, and $C(k)$ can be expressed by

$$\begin{aligned} C(k) &= R_1^*(k) R_2(k) \\ &= |H_l(k)|^2 |X_l(k)|^2 |X_{l+D}(k)|^2 e^{j2\pi\delta_r DN_u/N} \\ &+ \tilde{I}_l(k) + \tilde{Z}_l(k). \end{aligned} \tag{9}$$

IV. Simulation Results

The performance of the proposed RFO estimation method is evaluated in the computer simulation. 5G NR downlink system and CP-OFDM waveform is considered. Also, FFT size is $N = 2048$, and CP mode is used normal CP that is $N_{CP} = 144$. Subcarrier spacing is 15kHz which is operated sub-6GHz, and modulation scheme of transmission data is used QPSK modulation. Channel model is considered tapped delay line-A (TDL-A) model. The TDL-A channel model is characterized by a normalized minimum delay spread is 0, and normalized maximum delay spread is 9.6586. Scaling parameters for TDL-A channel model are considered the very short delay spread, nominal delay spread, very long delay spread [8]. The table I shows example scaling parameters for TDL-A channel model. Fig.1 presents the mean square error (MSE) performance of the proposed RFO estimation method versus signal to noise ratio (SNR) when the RFO= 0.01. The RFO is a value normalized to the subcarrier spacing in this simulation. The MSE performance of the proposed estimator is confirmed approximately 8×10^{-7} in very long delay spread of TDL-A model when SNR=20dB. Fig.2 shows the MSE performance of the proposed method versus SNR when the RFO= 0.1. The MSE performance is confirmed about 5×10^{-6} in very long delay spread of TDL-A model when SNR = 20dB. From the simulation result, the proposed scheme can be effective for the 5G NR system in the various delay spread conditions. From the simulation results, the possibility that the proposed scheme can be effectively used in various delay spread channel conditions of 5G NR system was shown.

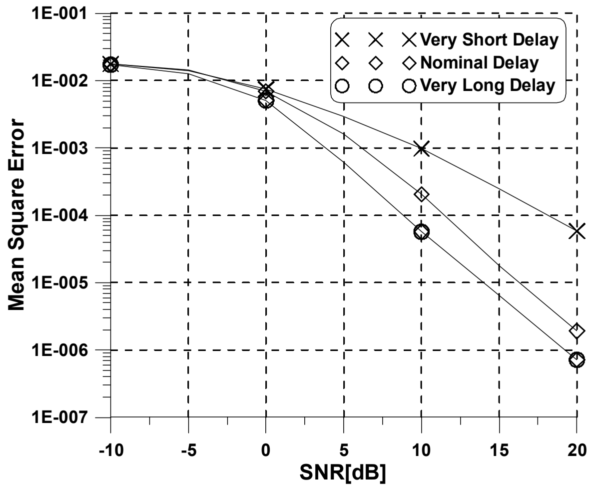

Fig. 1. Performance of the RFO estimator with RFO=0.01

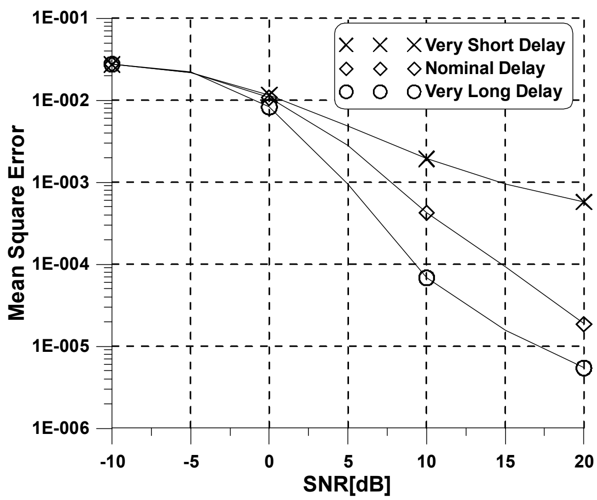

Fig. 2. Performance of the RFO estimator with RFO=0.1

V. Conclusion

In this paper, an efficient RFO estimation scheme is presented for 5G NR system. The proposed scheme exploits the two branches correlation operation by using PSS and SSS sequence. The performance of the proposed RFO estimator is evaluated by computer simulation. It has been shown from the presented results that the two branches correlation based proposed method is a good tool for RFO estimation. characterized

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