

Synchronization and Cell Search Procedure in 3GPP 5G NR Systems

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Abstract—In this paper, we design cell search and synchronization procedures involving the primary synchronization signal channel for the 3rd Generation Partnership Project (3GPP) 5th Generation (5G) New Radio (NR) Systems. More specifically, we present two approaches, one is based on auto-correlation and the other is based on cross-correlation. Moreover, to extract synchronization signals from large transmission band, an efficient filtering method is proposed. Numerical results are also provided to evaluate and compare the two different approaches.

Keywords—Synchronization, Cell Search, 5G NR

I. INTRODUCTION

In cellular systems, cell search and synchronization procedures are the very first step performed by a mobile device which tries to attain a connection with a base station. Orthogonal Frequency Division Multiple Access (OFDMA) systems such as the Long-Term Evolution (LTE) or the 5G New Radio (NR) system which are sensitive to frequency and timing errors, it is important to establish precise synchronization to avoid performance loss. To solve this problem, a lot of synchronization algorithms for the LTE systems have been proposed in the literatures [1]–[9]. However, the studies for the 5G NR systems have not been investigated yet.

There exist several differences between the synchronization signals for the 5G NR systems and those for the LTE. First, Zadoff-Chu sequences are applied for the synchronization signals in the LTE systems, the 5G NR systems, by contrast, adapt m-sequences which are more robust against time and frequency offsets. Second, the bandwidth assigned for the synchronization signals doubles to improve detection performance.

In addition, unlike the synchronization signals for the LTE systems designed to locate around center frequency only in transmission bands, the signals for the 5G NR systems can be assigned with variable frequency positions corresponding to the global synchronization channel Number (GSCN) [10] in the transmission bands. Since synchronization signals occupy a limited bandwidth in the bands, band-pass filters (BPF) may be utilized for cutting off the synchronization signal from a larger spectrum to mitigate the impact of noise and interference from non-synchronization signals.

On the other hand, in the 5G NR systems, the signals for synchronization transmit through the primary synchronization signal (PSS) channel and the secondary synchronization signal (SSS) channel. From the PSS detection, a cell sector ID, a symbol timing and a frequency location can be acquired. Then using these information, a full cell ID can be obtained by the SSS detection. Therefore, it is important note that the PSS related procedure is crucial as the first stage of cell search and synchronization. Therefore, focused on this importance of the PSS, in this paper, we present the two approaches for detecting PSS in the 5G NR systems: one is based on auto-correlation and the other is based on cross-correlation. From simulation results, it is shown that the auto-correlation based method is strong against frequency mismatch, and the cross-correlation based method is effective at low signal-to-noise ratio (SNR). In case of under 3GHz frequency bands also known as LTE re-farming bands, synchronization signals can be locate every 1.2MHz with $\pm 100\text{KHz}$ offset. For this case, the auto-correlation based approach can be applied once, while the cross-correlation based method requires three times considering the offsets.

In addition, due to the multiple candidates for synchronization signal location in frequency range, corresponding multiple BPFs may be required. It may increase a system complexity thus we also suggest a method to filtering the signals with only one low-pass filter.

The rest of this paper is organized as follows: In Section II, we describe the PSS channel structure considered in this paper. Section III proposes synchronization procedure for 5G NR systems. In Section IV, we provide numerical results to compare and evaluate the proposed schemes. Finally, Section V concludes the paper with further research directions.

II. PSS CHANNEL STRUCTURE

The sequences for a PSS denoted by $p_u[n]$ are composed of 127 samples of m-sequences, which is given by

$$p_u[n] = 1 - 2m[(n + 43u) \bmod 127] \quad \text{for } 0 \leq n \leq 126 \quad (1)$$

where $u \in \{0, 1, 2\}$ stands for cell sector ID and

$$m[n + 7] = (m[n + 4] + m[n]) \bmod 2$$

with the first 7 samples of $m[n]$ being $\{0, 1, 1, 0, 1, 1, 1\}$.

A PSS channel in frequency domain is consist of 240 subcarriers and, using (1), given by

$$D_u[f] = \begin{cases} p_u[f - 56], & 56 \leq f \leq 126 \\ 0, & \text{otherwise} \end{cases}.$$

The center position of a PSS channel indicated by $D_u[120]$ in the transmission band is defined as the frequency corresponding to Global Synchronization Channel Number (GSCN) denoted by f^{GSCN} . The PSS channel is combined with other channels, transformed to time-domain signals by inverse Fourier transform (IDFT) and transmitted to mobile devices.

III. SYNCHRONIZATION PROCEDURE

To obtain the synchronization from incoming samples in time-domain, Good correlation properties of m-sequence are utilized. When correlation of PSS sequence is performed with the input samples, the subcarriers except for PSS channel incur randomize noise effects against the synchronization process. In order to mitigate the impacts of noise contribution, especially in case of large subcarriers, before the time-domain correlation procedure, A discrete band pass filter (BPF) may be employed to reject all subcarriers over the PSS channel.

However, in the 5G NR systems, a frequency position of the PSS channel varies according to the GSCN, each frequency channel corresponding to all applicable GSCNs in the transmission band needs to be filtered with multiple BPFs.

A. Frequency Translation and Filtering

On hardware-limited mobile devices, to equip multiple BPFs may increase implementation complexity, thus, we propose a method to filter a desired frequency channel located in different position with a single low-pass filter (LPF).

By exploiting the fact that phase shift in time-domain equivalent to frequency translation, we can obtain signals $r_i[t]$ that subcarriers around frequency of GSCN i translate to the center frequency, from the original input signal $r[t]$ as

$$r_i[t] = \exp\left(-\frac{j2\pi\delta_i}{f_s}t\right) \cdot r[t]$$

where f_s represents a sampling rate and δ_i denotes the difference from the center frequency f^{Center} to the i -th GSCN frequency f_i^{GSCN} as $\delta_i = f_i^{\text{GSCN}} - f^{\text{Center}}$. Then, the low-pass filtered signal $r_i^{\text{LPF}}[t]$ is calculated as

$$r_i^{\text{LPF}}[t] = r_i[t] \otimes h^{\text{LPF}}[t]$$

where $\otimes$ stands for linear convolution operation and $h^{\text{LPF}}[t]$ indicates an LPF.

Since $r_i^{\text{LPF}}[t]$ only has significant informations around the center frequency, the down-sampling process with proper

rate may also be applied so as to reduce the computation complexity of correlation operations. Let us denote M as a down-sampling rate, the down-sampling signal $\bar{r}_i[t]$ is given by

$$\bar{r}_i[t] = r_i^{\text{LPF}}[Mt].$$

Note that, in case of 20MHz transmission band with 15KHz subcarrier spacing, a down-sampling rate is no less than $\frac{1}{16}$ considering the bandwidth of PSS channel.

B. Cross Correlation Criterion

At the mobile devices, for cross-correlation, the time-domain signal of $D_u[f]$ denoted by $d_u[t]$ is generated from N -points IDFT as

$$d_u[t] = \sum_{f=-\frac{N}{2}}^{\frac{N}{2}-1} D_u[f + 120] \cdot \exp\left(\frac{j2\pi f}{N}t\right)$$

where N indicates correlation window size and should be larger than a PSS signal length 127. Then using this, the cross-correlation based synchronization detection schemes are given by

$$(\hat{i}, \hat{u}, \hat{t}) = \underset{i, u, t}{\operatorname{argmax}} \sum_{k=0}^{N-1} \left| d_u[k] \cdot \bar{r}_u^*[k + t] \right|^2 \quad (2)$$

where $\hat{i}$, $\hat{u}$ and $\hat{t}$ indicate the estimated GSCN, the cell sector ID and the sample timing point, respectively.

C. Auto Correlation Criterion

Since PSS signals have periodicity, the synchronization can be acquired through auto-correlation of incoming samples. More specifically, the frequency location and symbol timing can be attained by auto-correlation based estimation as

$$(\hat{i}, \hat{t}) = \underset{i, t}{\operatorname{argmax}} \sum_{k=t}^{t+N-1} \left| \bar{r}_i[k] \cdot \bar{r}_i^*[k + L] \right|^2 \quad (3)$$

where $(\cdot)^*$ and $|\cdot|^2$ stand for complex conjugate and square norm, respectively, and L represents a period of the PSS signals. Then, utilized the output of (3), the cell sector ID can be estimated as

$$\hat{u} = \underset{u}{\operatorname{argmax}} \sum_{k=0}^{N-1} \left| D_u[k] \cdot \bar{R}_{i, \hat{t}}^*[k] \right|^2$$

where $\bar{R}_{i, \hat{t}}^*[f]$ stands for the frequency-domain signal, which is given by

$$\bar{R}_{i, \hat{t}}^*[f] = \sum_{t=-\frac{N}{2}}^{\frac{N}{2}-1} \bar{r}_i \left[\hat{t} + \frac{N}{2} + f \right] \cdot \exp\left(-\frac{j2\pi f}{N}t\right).$$

In the LTE re-farming bands, frequency points corresponding to each GSCN lie in groups of three, at intervals of

100KHz. Since the computation complexity of time-domain correlation process tends to be high, it may not be efficient to apply (2) to such closely spaced frequency point individually.

Instead, by selecting the middle among those three GSCN as a representative then applying (3), the representative frequency and time synchronization can be evaluated. Finally, the estimated cell sector ID and revision factor $\hat{\Delta}$ are obtained as

$$(\hat{u}, \hat{\Delta}) = \underset{u, \Delta}{\operatorname{argmax}} \sum_{k=0}^{N-1} \left| D_u[k + \Delta] \cdot \bar{R}_{i, \hat{\Delta}}^*[k] \right|^2$$

where $\Delta \in \{-7, 0, 7\}^1$, and the GSCN can be calculated as $\hat{i} + \frac{\hat{\Delta}}{7}$. Consequentially, we can reduce the number of time-correlation operation by one-third than applying (2).

Generally, it is known that cross-correlation shows better estimation accuracy than auto-correlation at low SNR, whereas auto-correlation is more efficient in presence of frequency offsets compared to cross-correlation [1]. It will be demonstrated in the next section.

IV. NUMERICAL RESULTS

In this section, we evaluate the detection probability (DP) performance of the two proposed cell search and synchronization schemes in the presence of CFO through Monte Carlo simulations. The environment for the simulation is based on the 5G NR standard and the parameters are listed in Table I.

In Figure 1, we can verify that the cross-correlation based method outperforms over the auto-correlation based method in the situation of 9KHz CFO. However, it is shown that the performance degradations of the cross-correlation is much more severe than that of the auto-correlation, and this tendency getting worse as CFO increase. To be specific about it, the performance decreases the amount of 5dB when the CFO increase from 9KHz to 11KHz at 80% DP with the cross-correlation, by contrast, only 1.8dB performance loss occurs with the auto-correlation. It is expected that with higher CFO than 11KHz the performance of the auto-correlation surpasses the cross-correlation.

From this simulation, we confirm that the cross-correlation based schemes are appropriate in SNR important environments, the auto-correlation based schemes are suitable for CFO dominant situations, which is tailed with our prediction.

V. CONCLUSIONS

In this paper, we have proposed cell search and synchronization algorithms involving the PSS channel for the 3GPP 5G NR Systems. Among two methods we

¹In strict sense, 100KHz interval not exactly counts for 7 subcarriers of 15KHz spacing, however, the difference can be cancelled by various carrier frequency offset (CFO) compensation methods in many literatures, which are out of scope of this paper.

TABLE I
SIMULATION ENVIRONMENT

Parameters	Value
Bandwidth	20MHz
Center Frequency	2.58GHz
Subcarrier Spacing	15KHz
GSCN	6462
LPF	64-Tap FIR w/ $\Omega_{cf} = \pi/8$
Down-sampling Rate	0.125
Correlation Window Size	256
Channel Mode	AWGN

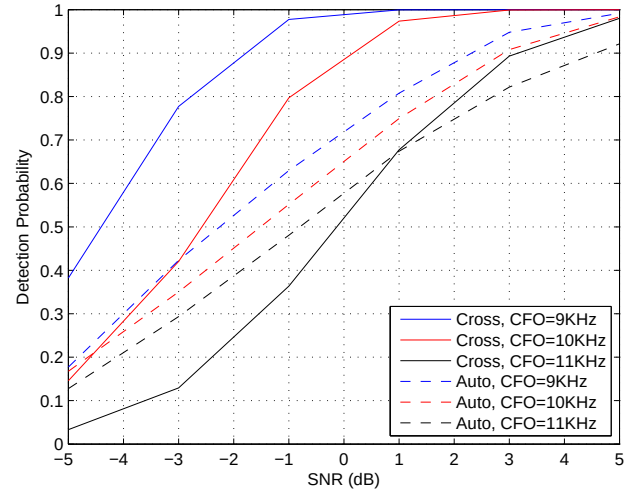


Fig. 1. DP of the proposed schemes in the presence of CFO

have proposed, it is confirmed that the cross-correlated based method is effective against noise and the auto-correlated based scheme is robust in presence of CFO. We also have found that an approach with auto-correlation is very proper for the LTE re-farming band. In order to reduce the complexity of mobile devices we have suggested an efficient way to filter input samples through only one LPF. Numerical results have been provided to compare and identify the performance of our schemes. It would be interesting to apply the proposed schemes to more realistic channel models. To design LPFs and find the optimal down-sampling rate for the proposed algorithms are another our interesting future direction.

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