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Synchronization for LTE-A System Downlink

A proposed novel method used at LTE wireless communications.

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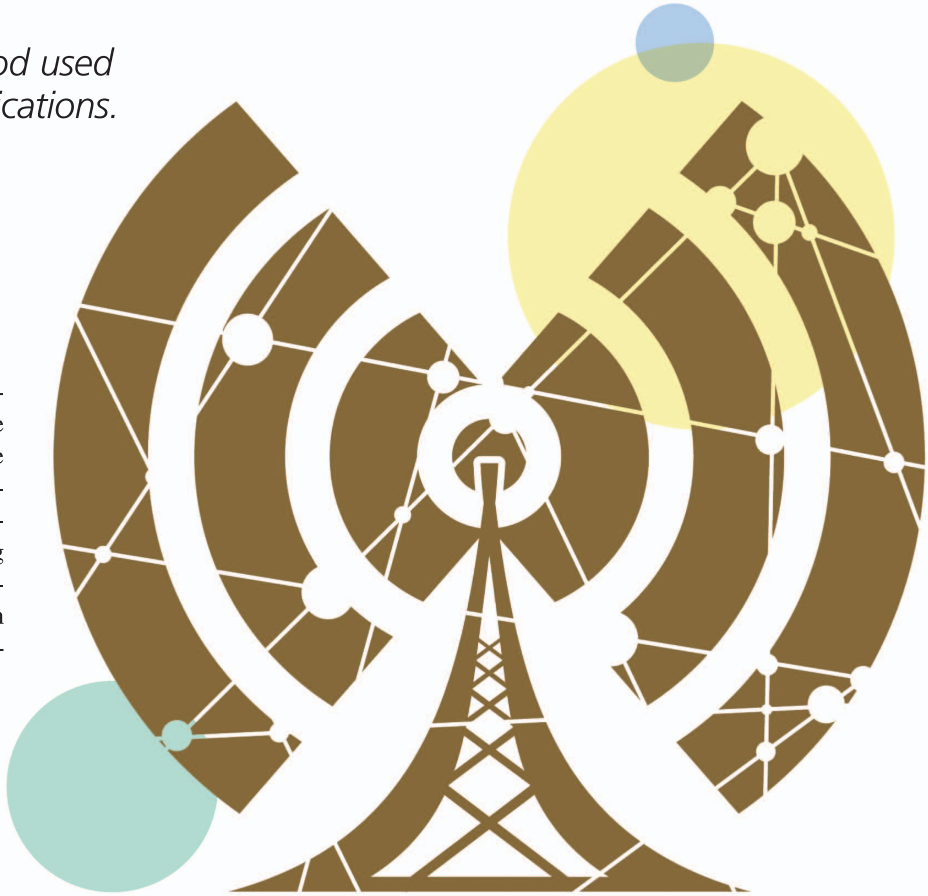

This article presents a synchronization method for the LTE system to determine time offset (TO) and fractional carrier frequency offset (FCFO) in multipath fading channels. With coarse and fine detection steps, the proposed TO estimation method exhibits better mean-square-error performance and at least 80% lower computational complexity than conventional methods. The proposed method can detect the channel length and uses the undistorted cyclic prefix region to detect FCFO. Results show that the proposed FCFO detection method performs better than conventional methods.

THE CHALLENGE OF SYNCHRONIZATION

With the recent widespread use of smartphones, system operators need to provide massive throughput and high-data-rate service to their subscribers. Many applications on a smartphone require substantial data transmission, for example, surfing the Internet, playing online games, and watching high-definition TV programs or movies (Figure 1). Conventional 3G wireless communication systems, which are based on the code division multiple access technique, cannot support the worldwide demand for such huge data-transmission services. To address this problem, 4G communication systems have been developed. According to the International Mobile Telecommunications-Advanced specifications, the transmission data rate of a 4G system can be up to 100 megabits/s for high-mobility scenarios and 1 gigabit/s for low-mobility scenarios.

LTE-Advanced (LTE-A), which is defined by the 3G Partnership Project (3GPP), has been deployed widely as a 4G wireless communication system to fulfill the higher-throughput requirement. The LTE-A system adopts orthogonal frequency division multiple access and multiple-input, multiple-output techniques to achieve high-speed service for user equipment (UE). LTE-A systems use a data-aided method via two signals to complete the synchronization: the primary synchronization signal (PSS) and the secondary synchronization signal.

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To achieve synchronization, two parameters must be estimated correctly: the TO (or sampling offset) and FCFO. The authors of [1] used the cross correlation between the received signal and the summation of three PSSs for TO detection. However, this method cannot reduce the effect of CFO and the multipath fading channels during TO estimation. The method in [2] provides a simultaneous detection of TO and CFO. However, computational complexity is a serious concern for this method. The authors of [3] used the cyclic prefix (CP) of the OFDM signal for FCFO detection.

Synchronization is a critical problem in all communication systems. With poor synchronization, the communication link between the UE and their serving-cell base station cannot be established [4], [5] (Figure 2). This article proposes a novel synchronization method using the PSS for the LTE system to estimate the TO and FCFO in multipath fading channels. We review the characteristics of the 3GPP PSS and illustrate the proposed method, which can also detect the channel length and uses the undistorted CP region to detect the TO and FCFO. We then present the simulation results to compare the estimation performance of our method versus that of previous related methods [1]–[3].

PROPOSED TO AND FCFO ESTIMATION METHOD

PSS REVIEW

According to the standard of a 3GPP LTE-A system [6], [7], the PSS is used to perform time and frequency synchronization in LTE-A systems, transmitted at intervals of 5 ms. The PSS inherits the symmetric property from the Zadoff–Chu sequence. In the frequency domain, PSS is symmetric with respect to the central frequency of the sequence. By applying the inverse fast Fourier transform, the PSS becomes symmetric in the time domain as well.

PROPOSED TO ESTIMATION METHOD

The symmetric property of the PSS gets distorted in a multipath scenario; however, the symmetric property still holds for the undistorted CP region between two successive PSSs without the Doppler effect. Therefore, the proposed method adopts the undistorted CP, instead of the whole CP, to conduct synchronization. Basically, the proposed method involves a coarse step and a fine step to complete TO estimation.

COARSE TO ESTIMATION

The coarse step calculates the correlation metric $T(\theta_c)$ of the received sampled signal $r(n)$,

$$T(\theta_c) = \sum_{n=1}^{N+N_{cp}} r((\theta_c - 1)\cdot N_d + n) r^*(L + (\theta_c - 1)\cdot N_d + n), \tag{1}$$

where N is the number of fast Fourier transform points, N_{cp} is the sample length of the CP, θ_c is the arbitrary sampling time index, and L denotes the interval between two successive PSSs. The coarse estimation function is $\hat{\theta}_c = \underset{\theta_c}{\operatorname{argmax}}(|T(\theta_c)|)$.

Assuming that there are M multipaths in the considered wireless channel, the received CP of the OFDM signal can be divided into two regions: one is distorted by the previous OFDM symbols, denoted as *contaminated CP*, and the other is the summation of the CPs with different multipath shifts, denoted as *undistorted CP*. Figure 3 depicts the undistorted and contaminated CP regions in the multipath fading channels used in this article. If θ_c is within the undistorted CP region, the defined metric $|T(\theta_c)|$ will have a peak value, which will indicate the coarse position estimation of the TO.

FINE TO ESTIMATION

After the coarse estimation $\hat{\theta}_c$, the fine detection step precisely detects the TO within the CP range of the coarse estimation. Let the normalized received signal be $r_{nor}(n) = (r(n)/|r(n)|)$, where we use r_{nor} instead of r within a CP range around the $\hat{\theta}_c$

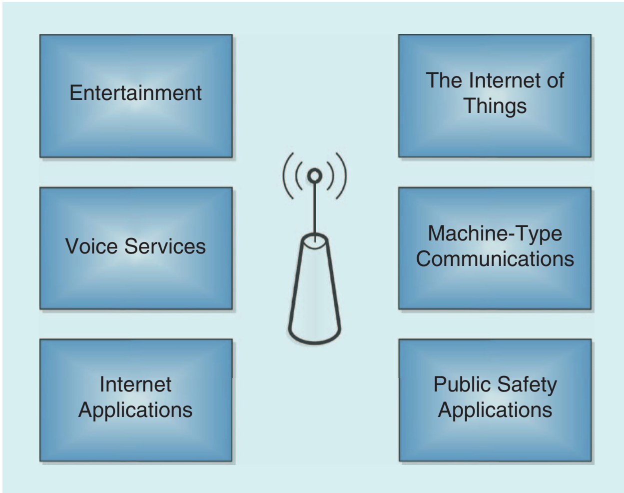

FIGURE 1. The applications of modern wireless communications.

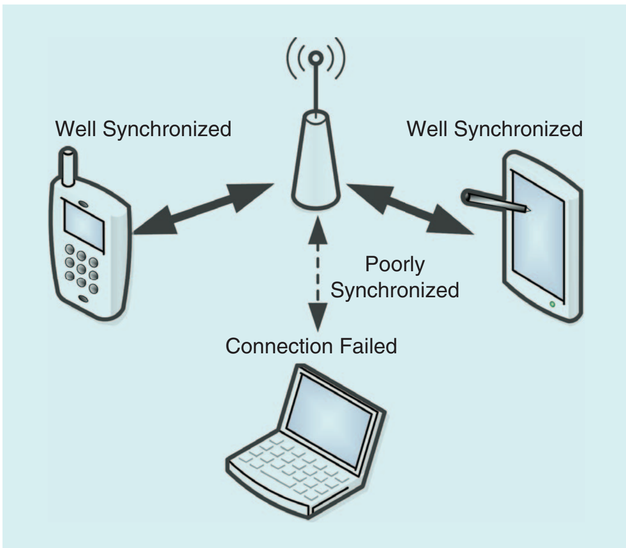

FIGURE 2. Synchronization establishment.

in (1) for the fine TO estimation. The final decided starting position of the signal is $\hat{\theta}_f = \hat{n}_{\tau s} - \{N_{cp} - [\hat{n}_{\tau e} - \hat{n}_{\tau s}]\} = \hat{n}_{\tau e} - N_{cp}$, where $\hat{n}_{\tau s}$ and $\hat{n}_{\tau e}$ denote the estimated locations at the beginning and at the end of the undistorted CP region.

PROPOSED FCFO ESTIMATION METHOD

Based on the proposed TO estimation result, the undistorted CP region can be acquired. When only the undistorted CP region is used, the proposed FCFO detection method can be expressed as

$$\hat{\varepsilon}_F = \tan^{-1}\left(\frac{-\mathrm{Im}(\phi)}{\mathrm{Re}(\phi)}\right), \phi = \sum_{n=\hat{n}_{\tau s}}^{\hat{n}_{\tau e}} |P_u(n)|^2 e^{-j2\pi(\varepsilon_F)}, \qquad (2)$$

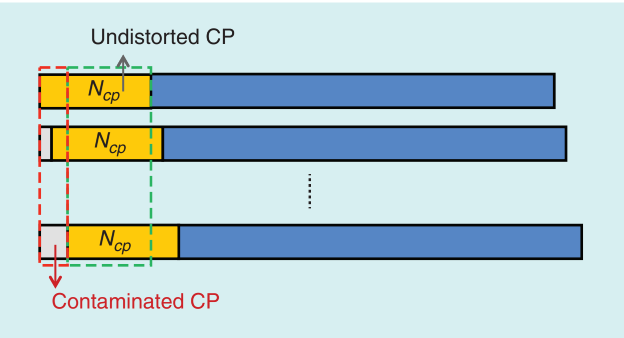

FIGURE 3. The undistorted and contaminated CP regions.

Table 1. Simulation parameters.

Parameter	Value
Transmission bandwidth	1.4 MHz
Carrier frequency	2 GHz
CP type	Normal, extended
Moving speed	100 km/h
Modulation	QPSK
N	128
$N_{cp(\mathrm{normal})}$	9
$N_{cp(\mathrm{extended})}$	32
Cell-ID1	10
Cell-ID2	0, 1, 2 ($u = 25, 29, 34$)
$\triangle f$	15 kHz
T_s	1/(15,000·128) s
Doppler shift	185.19 Hz
FCFO	0.4

QPSK: quaternary phase-shift keying; ID1: Identification_1; ID2: Identification_2.

where $\mathrm{Re}(\phi)$ and $\mathrm{Im}(\phi)$ are the real and imaginary parts of ϕ and $P_u(n)$ is the PSS with root index u.

In summary, the proposed method uses two successive PSSs to conduct synchronization. By using the autocorrelation function of the received signal, the undistorted CP region can be determined, which can help the receiver complete the TO and FCFO estimation.

COMPUTER SIMULATIONS

In this section, three channel-delay profiles, defined by previous 3GPP studies [6], are adopted to compare the performance of the proposed and the literature methods, that is, extended pedestrian A, extended vehicular A (EVA), and extended typical urban (ETU) models. The simulation parameters in the proposed TO and FCFO estimation method are listed in Table 1.

Figure 4 presents a comparison of the simulation results of TO estimation between the methods in [1] and [2] and our proposed scheme. It indicates that the proposed TO estimation method exhibits the best performance, which comes from the fact that the proposed method adopts the undistorted CP, instead of the whole CP, to conduct synchronization. Since the methods in [1] and [2] do not consider the CFO and multipath effect during detection, their performances are poor.

The performance of the proposed method will not depend significantly on the value of root index u of the PSS. However, the compared conventional methods from [1] and [2] depend notably on the symmetric property of the PSS. Actually, it is another advantage of the proposed method that it

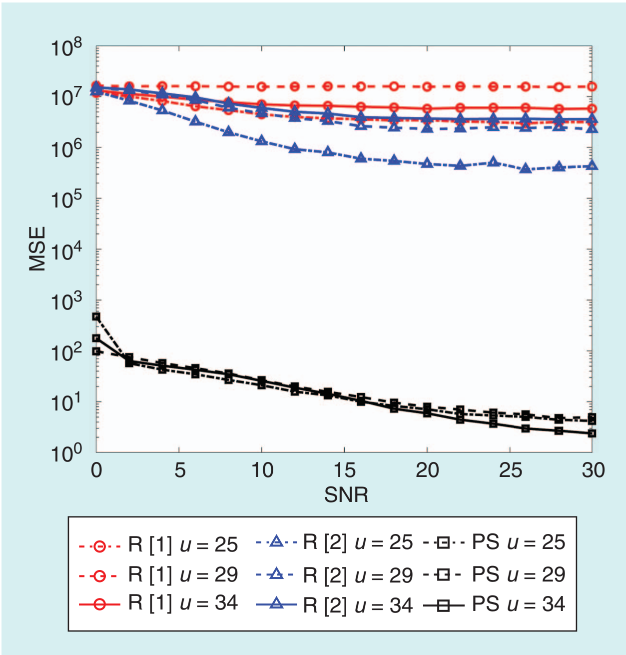

FIGURE 4. TO detection compared with the EVA model. MSE: mean-square error; PS: proposed scheme; R: reference; SNR: signal-to-noise ratio.

has a robust synchronization performance, regardless of the selected root index u.

Because these previous methods need to search and calculate all possible starting positions of the received signal, they are more complex than the proposed method. Assume that the complexities for addition, subtraction, multiplication, and division are the same and are set to 1; the required computational complexities for these methods are listed in Table 2. For example, if the parameters in Table 1 are inserted into the equations in Table 2 and the required complexity for the proposed method is assumed to be 100%, the complexity for the methods in [1] and [2] will be more than three times and one and one-half times greater, respectively.

Figure 5 shows a comparison of the mean-square error performance for the proposed scheme and the method in [3]. The main difference between the two methods is that the method in [3] adopts the whole CP signal to conduct FCFO estimation. Method [3] has poorer performance than the proposed method, especially in long delay profiles, such as the EVA and ETU scenarios. On the other hand, the proposed FCFO method uses the undistorted CP region only, rather than using the whole CP, to avoid multipath distortions. Simulation results show that using only the undistorted CP region provides a more precise estimation than using the whole CP signal.

Table 2. Computational complexity analysis.

Method	Complexity
Proposed	$\left\lfloor \frac{L-N}{N_d} \right\rfloor \times (2N-1+4)+(2N_{cp}+N)\times 5+(2N_{cp})\times(2N-1+3+4)$
[1]	$(L-N)\times(2N-1)$
[2]	$(L-N)\times(N-1)$

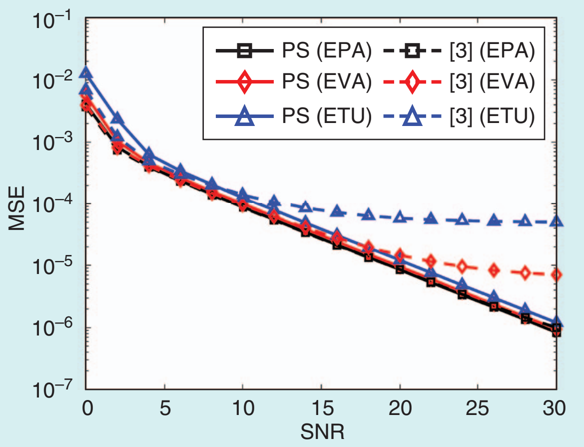

FIGURE 5. Comparisons of FCFO detection. EPA: extended pedestrian A; MSE: mean-square error; PS: proposed scheme; SNR: signal-to-noise ratio.

CONCLUSION

This article proposes a novel synchronization method for TO and FCFO estimation in LTE systems. The proposed TO detection method uses the repeating PSS synchronization signals for TO estimation in multipath fading channels. The coarse and fine detection steps of the proposed method allow it to offer better MSE performance and at least 80% lower computational complexity than the methods outlined in the literature. In addition, the proposed method can detect the channel length (or the undistorted region) and uses the undistorted CP region for FCFO estimation. Results show that the proposed method has better performance than previous methods, which use the whole CP, especially in the long-delay-channel scenarios.

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