LTE signal processing for positioning

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Abstract. Long Term Evolution (LTE) networks are rapidly deploying around the world. In the Czech Republic the frequency band 20 (800 MHz) is used, which is interesting for positioning, because there is good coverage around whole Czech territory. The LTE uses the OFDM modulation.

In this paper we describe algorithm for synchronization of LTE signals. A part of this paper is also an algorithm for Cell ID detection, which is important for synchronization of LTE signals, and may serve to determining the position with Cell ID method [11]. Knowledge of Cell ID is important for another signal processing, for example for detection synchronizations and positions signals.

Keywords
Matlab, LTE, signal processing, signal of opportunity, cell ID detection.

1. Coarse synchronization

1.1 PSS signal detection and beginning of OFDM symbol

The first step of signal processing of LTE signals is coarse synchronization. For coarse synchronization in LTE is used Primary Synchronization Signal (PSS). This signal uses a Zadoff-Chu sequence in frequency domain. LTE uses sequences with roots 25, 29 and 34 for sector of the cell N_{ID} = 0, 1 or 2. The PSS consists of 62 samples Zadoff-Chu sequence (d(0) – d(30) and d(31) – d(61) in Fig. 1). Then zeros (DC and other samples) are added. One sample in frequency domain corresponds to a signal transmitted on one subcarrier.

![Fig. 1 - Frequency domain representation of PSS](image)

For coarse synchronization we generate replica of all three PSS signals. After that we transform these replicas to time domain using inverse Fast Fourier Transform (IFFT).

Then we compute correlation function of received signal and generated replica of PSS in time domain (1).

\[
R(k) = \sum_{i=0}^{N} s(i) PSS^*(i + k)
\]

Where:
- PSS* - complex conjugate replica of PSS
- s(i) – received signal
- N – number of samples in one OFDM symbol

Computing of correlation in time domain is extended of correlation received signal with frequency offset. Step of computed frequency offset is spacing between subcarriers (which is Δf = 15 000 Hz for LTE with normal cyclic prefix (CP)). Frequency offset is simulated by (2).

\[
s_{\text{offset}}(i) = s(i) e^{j2\pi f_{\text{offset}} \Delta f T_s i}
\]

Where:
- s_{\text{offset}}(i) – signal with frequency offset
- s(i) – received signal
- f_{\text{offset}} – multiple of subcarrier spacing offset
- Δf – subcarrier spacing
- T_s – duration of one sample

Results of this algorithm are three 2D correlation functions. Maximum of these correlations detects sector of serving Cell, beginning of OFDM symbol with PSS signal and integer part of frequency offset in multiple of subcarriers spacing.

1.2 Detection group of Cell

When we know beginning of the OFDM symbol and a sector of serving Cell, we can detect a secondary synchronization signal (SSS). The SSS represents group of Cell (N_{ID} from 0 to 167). The SSS is based on maximum length gold sequences (m-sequences). The SSS signal is represented by ±1 in frequency domain. It has the same length like the PSS. The SSS signal is dependent on Cell sector, Cell group and slot in LTE frame. The SSS is received in OFDM symbol before symbol with a PSS.

For the SSS detection we use circular correlation in frequency domain using IFFT (3).
\[ corr = \text{IFFT}\{ S(f) SSS^* \} \quad (3) \]

Where:
- \( S(f) \) – received OFDM symbol with the SSS in the frequency domain
- \( SSS^* \) - replica of the SSS signal

We compare a received SSS signal with all 168 possible sequence for slot 0 and slot 10 in LTE frame. The result of this algorithm is two 2D correlation function. One maximum detects group of Cell and simultaneously slot of the LTE frame.

1.3 Cell ID detection

Then we have all needed information for determining Cell ID according to (4). Cell ID assumes values from 0 to 503.

\[ \text{Cell ID} = 3 \cdot N_{ID2} + N_{ID1} \quad (4) \]

1.4 Correction beginning of symbol with an accuracy of one sample

After detection of the group of Cell ID we compute correlation between replica of detected SSS signal and five times received OFDM symbol with SSS, which beginning is shifted by -2 till 2 samples. We compare first samples of these five correlation functions. The maximum is signalizing real shift.

\[ Y = \frac{S(\text{CSR})}{\text{replica(\text{CSR})}} \quad (5) \]

Where:
- \( Y \) – wiped off signal
- \( S(\text{CSR}) \) – received CSR signal
- \( \text{replica(\text{CSR})} \) – generated replica of CSR signal

From wiped off signal we can calculate estimate of residual fractional time offset of beginning of symbol according to (6).

\[ \hat{\tau} = \arg \max \left\{ \sum_{k \in K} \sum_{n \in N} |Y(k, n) e^{-j2\pi n \tau / N}|^2 \right\} \quad (6) \]

Where:
- \( Y(k, n) \) – wiped off received signal
- \( \tau \) - residual fractional time offset
- \( k \) – index of OFDM symbol
- \( n \) – index of subcarrier
- \( K \) – set of OFDM symbols
- \( N \) – set of subcarriers
- \( N \) – length of OFDM symbol in samples

After estimate offset we can compensate it according to (7).

\[ S(k, n) = S(k, n)e^{-j2\pi \tau / N} \quad (7) \]

2.2 Fine synchronization

After construction of the LTE frame, we can compensate residual fractional time offset beginning of OFDM symbol and fractional carrier frequency offset (CFO) [3].

For this compensation we use Cell Specific Reference Signals (CSR). From knowledge of Cell ID we can generate replica of CSR signals. Then we divide received CSR signals by generated replica of CSR. This operation is denoted “wipe-off”. This wiped-off signal is denoted \( Y \).

\[ Y = \frac{S(\text{CSR})}{\text{replica(\text{CSR})}} \]

Where:
- \( Y \) – wiped off signal
- \( S(\text{CSR}) \) – received CSR signal
- \( \text{replica(\text{CSR})} \) – generated replica of CSR signal

After estimate offset we can compensate it according to (7).

\[ S(k, n) = S(k, n)e^{-j2\pi \tau / N} \]

We can also compensate fractional CFO. It is estimate of phase difference between neighboring OFDM symbols according to (8).

\[ \hat{\nu} = \frac{N}{2\pi N_{\text{slot}}} \arg \left\{ \sum_{k \in K} \sum_{n \in N} Y'(k - 7, n) Y(k, n) \right\} \quad (8) \]
Where:

\( \hat{\nu} \) – estimated CFO

\( N \) – length of OFDM symbol in samples

\( N_{\text{slot}} \) – number of samples in one LTE slot

\( P \) – number of phase different

\( Y(k,n) \) – wipped off received signal

\( K \) – set of OFDM symbols

\( N \) – set of subcarriers

\( k \) – index of OFDM symbol

\( n \) – index of subcarrier

We use only the first OFDM symbol of all LTE slots. Then we can compensate CFO according to (9).

\[
S(k, n) = S(k, n)e^{-j2\pi k \nu / N}
\] (9)

**Conclusion**

In this paper we described algorithm for signal processing of LTE signals. In the first step we used coarse synchronization, which is required for processing LTE signal. Then we described algorithm for Cell ID detection. This is important for next steps in signal processing. In the last part of this paper we described algorithm for fine synchronization, which compensate residual CFO and residual fractional time offset of OFDM symbol.

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**References**


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