Chapter 3

The Downlink Synchronization Signals

According to [2], 504 physical-layer cell identities are assigned to LTE which simplifies the cell search procedure. Every UE needs to register to a cell, so every cell has its unique cell-ID.

The UE attaches to the cell when it is switched on, lost the connection with any cell and for the handover process. The physical-layer cell identities (N_{ID}^{cell}) are divided into 168 unique physical layer cell identity groups $N_{ID}^{(1)}$, and every group consists of three physical layer identities $N_{ID}^{(2)}$, as follows:

$$N_{ID}^{cell} = 3N_{ID}^{(1)} + N_{ID}^{(2)}$$

As will be shown the primary synchronization sequence is used to estimate the physical layer identities (also called sector index within a base station) and the secondary synchronization sequence is used to estimate the physical layer cell identity group.

Figure 3.1 shows the root cause of this structure and the relation between the base stations and the sectors. Each sector index (physical layer identity) represents a sector within a base station and each cell identity group represents a base station.

Note that according to [2] there are 504 different downlink reference-signal sequences defined for LTE, where each sequence corresponds to one out of 504 different physical-layer cell identities so after the cell search procedure, we can conclude reference-signal sequence is used within the cell as well as the start of the reference-signal sequence [7].

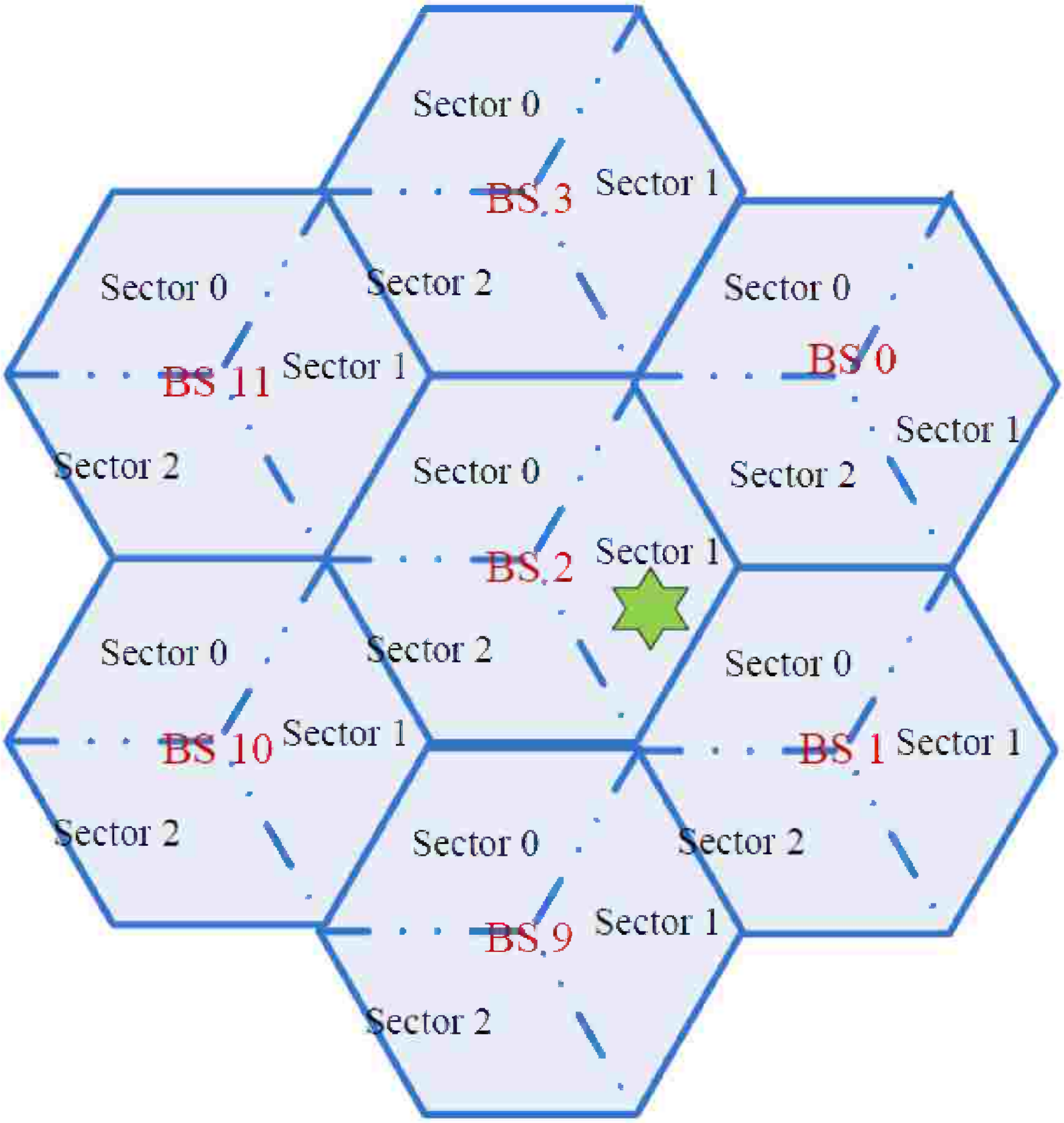

Figure 3.1 The relation between sectors and base stations

To transmit this information from the E-UTRAN Node B (eNB) to the UE, we transmit two types of signals. The primary synchronization signal and the secondary synchronization signal, which carry the physical layer identity and the physical layer cell identity group respectively. The complete cell search is done through detecting these two signals within the receiver in the DL frame, and we can use these signals to make the timing symbol synchronization as will be seen in chapter 4.

This cell search procedure is repeated periodically until either the serving cell quality becomes satisfactory again, or the UE moves to another serving cell.

The PSS uses sequences known as Zadoff–Chu. This category of sequences is widely used in LTE, including random access preambles and the uplink reference symbols in addition to the PSS [2] due to their good autocorrelation and cross correlation properties as will be seen in the next section. Therefore, the following section is devoted to an explanation of the fundamental principles behind these sequences, before discussing the specific constructions of the PSS and SSS sequences in the subsequent sections.

3.1. Zadoff–Chu Sequences

Zadoff–Chu (ZC) sequences (also known as Generalized Chirp-Like (GCL) sequences) are named after the papers [14] and [15]. They are non-binary unit-amplitude sequence, which satisfy a Constant Amplitude Zero Autocorrelation (CAZAC) property.

The ZC sequence of odd-length N_{ZC} is given by

$$a_q(n) = e^{-j2\pi q\frac{n(n+1)/2+ln}{N_{ZC}}} \tag{5}$$

where q ∈ {1, . . . , N_{ZC}− 1} is the ZC sequence root index, n = 0, 1, . . . , N_{ZC} − 1, l ∈N is any integer. In LTE l = 0 is used for simplicity.

ZC sequences have the following important properties.

- A ZC sequence has constant amplitude, and its NZC-point DFT also has constant amplitude. The constant amplitude property limits the Peak-to-Average Power Ratio (PAPR).
- ZC sequences of any length have 'ideal' cyclic autocorrelation (i.e. the correlation with the circularly shifted version of itself is a delta function). This property is of major interest when the received signal is correlated with a reference sequence and the received reference sequences are misaligned as will be shown.
- The absolute value of the cyclic cross-correlation function between any two ZC sequences is constant and equal to $1/\sqrt{N_{ZC}}$, if |q1 − q2| (where q1 and q2 are the sequence indices) is relatively prime with respect to N_{ZC} (a condition that can be easily guaranteed if N_{ZC} is a prime number). The cross-correlation of $1/\sqrt{N_{ZC}}$ at all lags achieves the theoretical minimum cross-correlation value for any two sequences that have ideal autocorrelation.

Selecting N_{ZC} as a prime number results in $N_{ZC}- 1$ ZC sequences which have the optimal cyclic cross-correlation between any pair. However, it is not always convenient to use sequences of prime length. In general, a sequence of non-prime length may be generated by either cyclic extension or truncation of a prime-length ZC sequence. Cyclic extension or truncation preserves both the constant amplitude property and the zero cyclic autocorrelation property for different cyclic shifts.

3.2. Primary Synchronization Signal

According to [2] and [16] the primary synchronization signal d(n) is constructed from a frequency-domain Zadoff-Chu (ZC) sequence of length 63, with the middle element punctured to avoid transmitting on the DC-subcarrier.

$$d_u(n) = \begin{cases} e^{-j\frac{\pi u n(n+1)}{63}} & n = 0,1,\dots.30 \\ e^{-j\frac{\pi u(n+1)(n+2)}{63}} & n = 31,32,\dots.61 \end{cases} \quad (6)$$

Where the Zadoff-Chu root index u is given in table 3.1

$N_{ID}^{(2)}$	Root index
0	25
1	29
2	34

Table 3.1 Zadoff-chu root index “u”

As mentioned above, these sequences have a good autocorrelation and cross correlation properties, and the important property that these sequences have a low-frequency offset sensitivity and flat frequency-domain autocorrelation property. These properties are very important to achieve a good initial time synchronization in the receiver in short time and make the sequence robust against frequency drifts.

The primary synchronization signal is mapped on the 62 mid sub-carriers located around the DC-subcarrier in frequency domain. The sequence is mapped to the last OFDM symbol in slot 0 and slot 10 (in sub-frame 0 and 5) in time domain.

3.3. Secondary Synchronization Sequence

The Secondary synchronization sequences are based on maximum length sequences, known as M-sequences, which can be created by cycling through every possible state of a shift register of length n. This results in a sequence of length $2^n - 1$.

The sequence $d(0),...,d(61)$ used for the second synchronization signal is an interleaved concatenation of two length-31 binary sequences. The concatenated sequence is scrambled with a scrambling sequence given by the primary synchronization signal [2].

The combination of two length-31 sequences defining the secondary synchronization signal differs between sub-frame 0 and sub-frame 5 according to

$$d(2n) = \begin{cases} s_0^{(m_0)}(n)c_0(n) & \text{in subframe 0} \\ s_1^{(m_1)}(n)c_0(n) & \text{in subframe 5} \end{cases}$$
$$d(2n+1) = \begin{cases} s_1^{(m_1)}(n)c_1(n)z_1^{(m_0)}(n) & \text{in subframe 0} \\ s_0^{(m_0)}(n)c_1(n)z_1^{(m_1)}(n) & \text{in subframe 5} \end{cases} \quad (7)$$

Where $0 \le n \le 30$. The indices m_0 and m_1 are derived from the physical-layer cell-identity group $N_{\text{ID}}^{(1)}$ according to

$$m_0 = m' \bmod 31$$
$$m_1 = \left(m_0 + \lfloor m'/31 \rfloor + 1\right) \bmod 31 \quad (8)$$
$$m' = N_{\text{ID}}^{(1)} + q(q+1)/2, \quad q = \left\lfloor \frac{N_{\text{ID}}^{(1)} + q'(q'+1)/2}{30} \right\rfloor, \quad q' = \lfloor N_{\text{ID}}^{(1)}/30 \rfloor$$

The two sequences $s_0^{(m_0)}(n)$ and $s_1^{(m_1)}(n)$ are defined as two different cyclic shifts of the m-sequence $\tilde{s}(n)$ according to

$$s_0^{(m_0)}(n) = \tilde{s}\left((n+m_0) \bmod 31\right)$$
$$s_1^{(m_1)}(n) = \tilde{s}\left((n+m_1) \bmod 31\right) \quad (9)$$

Where $\tilde{s}(i) = 1 - 2x(i)$, $0 \le i \le 30$, is defined by

$$x(\bar{i}+5) = \left(x(\bar{i}+2) + x(\bar{i})\right) \bmod 2, \qquad 0 \le \bar{i} \le 25 \quad (10)$$

With initial conditions $x(0)=0, \quad x(1)=0, \quad x(2)=0, \quad x(3)=0, \quad x(4)=1$.

The two scrambling sequences $c_0(n)$ and $c_1(n)$ depend on the primary synchronization signal and are defined by two different cyclic shifts of the m-sequence $\tilde{c}(n)$ according to

$$c_0(n) = \tilde{c}((n + N_{\mathrm{ID}}^{(2)}) \bmod 31)$$
$$c_1(n) = \tilde{c}((n + N_{\mathrm{ID}}^{(2)} + 3) \bmod 31) \tag{11}$$

where $N_{\mathrm{ID}}^{(2)} \in \{0,1,2\}$ is the physical-layer identity within the physical-layer cell identity group $N_{\mathrm{ID}}^{(1)}$ and $\tilde{c}(i) = 1 - 2x(i)$, $0 \le i \le 30$, is defined by

$$x(\bar{i} + 5) = (x(\bar{i} + 3) + x(\bar{i})) \bmod 2, \qquad 0 \le \bar{i} \le 25 \tag{12}$$

With initial conditions $x(0) = 0, \quad x(1) = 0, \quad x(2) = 0, \quad x(3) = 0, \quad x(4) = 1$.

The scrambling sequences $z_1^{(m_0)}(n)$1 and $z_1^{(m_1)}(n)$ are defined by a cyclic shift of the m-sequence $\tilde{z}(n)$ according to

$$z_1^{(m_0)}(n) = \tilde{z}((n + (m_0 \bmod 8)) \bmod 31)$$

$$z_1^{(m_1)}(n) = \tilde{z}((n + (m_1 \bmod 8)) \bmod 31) \tag{13}$$

Where m_0 and m_1 are obtained from Table 6.11.2.1-1 and $\tilde{z}(i) = 1 - 2x(i)$, $0 \le i \le 30$, is defined by

$$x(\bar{i} + 5) = (x(\bar{i} + 4) + x(\bar{i} + 2) + x(\bar{i} + 1) + x(\bar{i})) \bmod 2, \qquad 0 \le \bar{i} \le 25 \tag{14}$$

With initial conditions $x(0) = 0, \quad x(1) = 0, \quad x(2) = 0, \quad x(3) = 0, \quad x(4) = 1$.

The secondary synchronization signals also have good frequency domain properties and a flat spectrum in frequency domain [1]. Like primary synchronization signals, the secondary synchronization signals have a low-frequency offset sensitivity, so we can detect the sequence in presence of frequency drifts.

The secondary synchronization signal is mapped like the primary synchronization signal on the 62 mid sub-carriers in the frequency domain around the DC-subcarrier. In time domain the first sequence is mapped to the OFDM symbol before the primary sequence in slot 0, and the second sequence is also mapped to the OFDM symbol before the primary sequence in slot 10.

The mappings of the primary synchronization sequence and the secondary synchronization sequence are illustrated in figure 3.2.

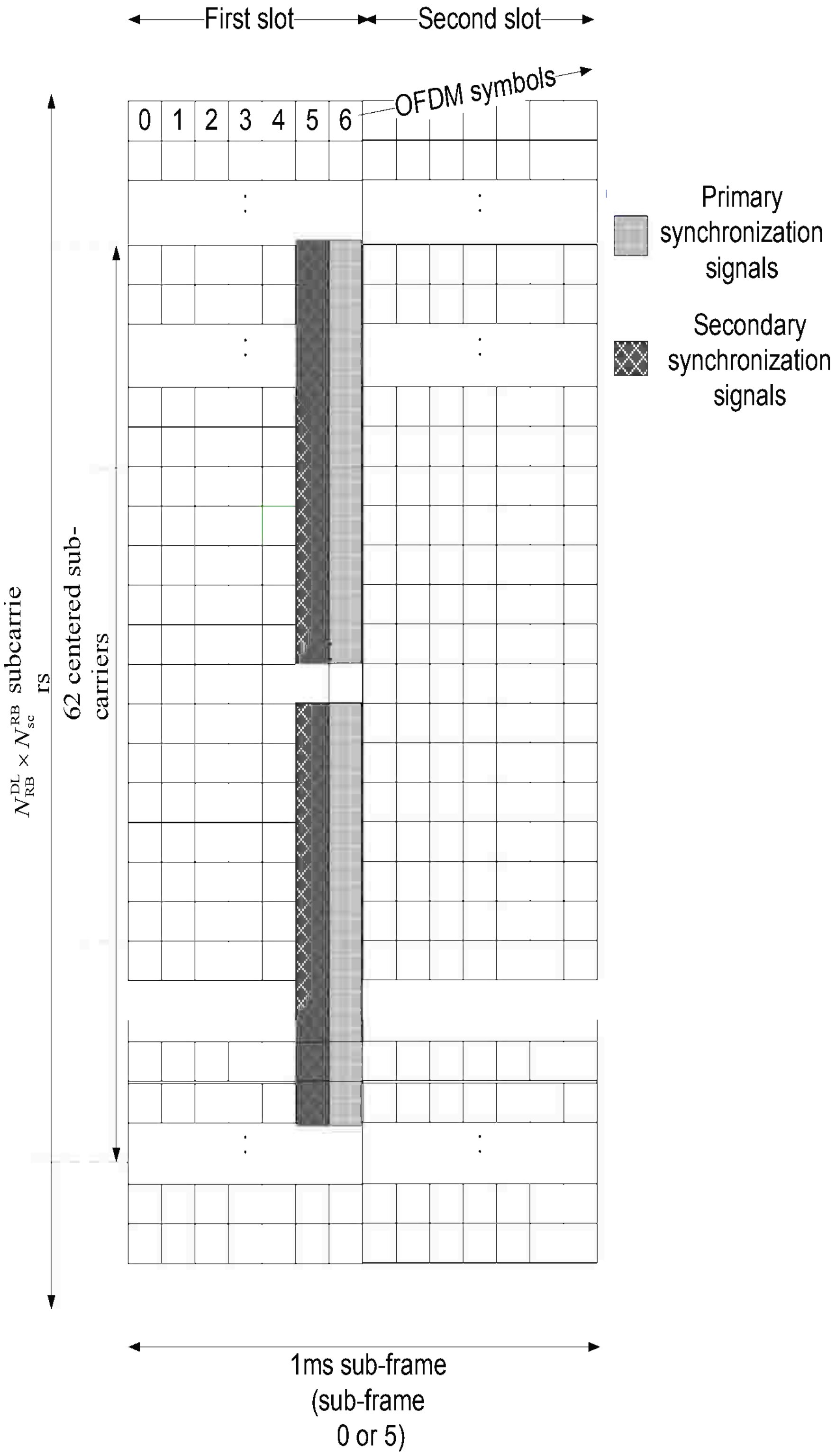

Figure 3.2 The primary and secondary synchronization signals mapping in the resource grid of the LTE down link in sub-frame 0 and 5.