

SIMULTANEOUS CELL GROUP AND CYCLIC PREFIX DETECTION METHOD, APPARATUS AND SYSTEM

TECHNICAL FIELD

5 The present invention relates generally to communication systems and components and, more particularly, to wireless communication systems and components adapted to use Orthogonal Frequency Division Multiplexing (OFDM) modulation techniques.

BACKGROUND

10 Evolving mobile cellular standards such as Global System for Mobile Communications (GSM) and Wideband Code Division Multiple Access (WCDMA) will likely require modulation techniques such as OFDM in order to deliver higher data rates. OFDM is a method for multiplexing signals which divides the available bandwidth (BW) into a series of frequencies known as sub-carriers.

15 In order to ensure a smooth migration from existing cellular systems to high capacity, high data rate systems using existing radio spectrum, new systems must be able to operate on a flexible BW. Third generation Long Term Evolution (LTE) has been proposed as a new flexible cellular system. LTE is intended as an evolution of the WCDMA standard. LTE will likely use OFDM and operate on BWs spanning from 1.25 MHz to 20
20 MHz. Data rates of up to 100 Mb/s will be possible in the high BW LTE service.

 Low rate services such as voice are also expected to use LTE. Because LTE is designed for Transmission Control Protocol/Internet Protocol (TCP/IP), voice over IP (VoIP) will likely be the service carrying speech.

 One important aspect of LTE is the mobility function. As a result, synchronization
25 symbols and cell search procedures are of major importance in order for an apparatus, such as a user equipment (UE), to detect and synchronize with other cells.

 The proposed cell search scheme for LTE is as follows:

1. Detect symbol timing for new cell using the primary synchronization signal (P-SyS). Furthermore, because there are three P-SyS, the UE also detects which of the P-SyS

have been transmitted from the cell. The index of each P-SyS identifies the cell ID within a group. P-SyS is transmitted every 5 milliseconds (ms).

2. Detect frame timing and cell group using the secondary synchronization signal (S-SyS). The frequency domain representation of P-SyS is used as phase reference and then the S-SyS detection (correlation to different S-SyS sequences) is performed in the frequency domain.

3. From steps (1) and (2), the cell ID is detected.

4. Read broadcast channel (BCH) to receive cell specific system information

In LTE, there will be a possibility of using a short cyclic prefix (CP) or a long CP length. The short CP length (4.7 microseconds (μ sec)) will be used for small cells and the long CP length (16.7 μ sec) will be used for large cells and broadcast services. The intention is that the UE should detect the cell specific CP length blindly. This is preferably performed prior to detecting the frame timing and cell group using the secondary S-SyS (step 2 of the cell search scheme described above). Blind CP detection can be made in the time domain, as seen in the block diagram 100 of Figure 1. In this case, the UE performs autocorrelation of the received signal with distance T_u corresponding to the OFDM symbol length. The correlation is summed and the power (absolute value) is calculated. Peaks 101A, 101B will arrive with a distance of $T_u + T_g$ where T_g is the CP length. From that, the CP length can be computed at module 102. This time-domain approach is suitable for a single frequency, synchronized, network, such as digital video broadcasting-handheld (DVB-H), where signals from all cells are transmitted with the same CP length and are synchronized. However, this will typically not be the case in LTE. In LTE the cells can be operated in an asynchronous mode and different cells might have different CP lengths. This, in turn, will result in a risk of multiple correlation peaks making the time domain CP length detection much more complicated.

Figure 2 shows the synchronization signal (SyS) structure 200 in LTE, for both the long CP 201 and short CP 202 case. A slot with a length of 0.5 ms in LTE consists of 7 OFDM symbols in the short CP case and 6 OFDM symbols in the long CP case. Every 10th slot, that is every 5 ms, the SyS is transmitted. For frequency division duplex (FDD) (full

duplex) in LTE, P-SyS is transmitted in the last OFDM symbol in the slot and the S-SyS in the second to last OFDM symbol. For time division duplex (TDD), the S-SyS is transmitted in the last OFDM symbol and P-SyS is transmitted in the first OFDM symbol in the next slot.

- 5 It would be advantageous to have a low complexity blind CP detection method and apparatus that is robust also in scenarios existing in OFDM cellular system like LTE. The present invention provides such a method and apparatus.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

- 10 FIG. 1 illustrates a block diagram for performing blind CP detection in the time domain;

 FIG. 2 illustrates the synchronization signal (SyS) structure in LTE, for the long CP and short CP case;

- FIG. 3 illustrates, in detail, the SyS timing relationships for the long CP and short CP, with an overlay of the S-SyS FFT timing used by the present invention;

 FIG. 4 provides a flowchart of the method of the present invention;

 FIG. 5 is a block diagram of an apparatus adapted to implement the method of the present invention

- FIG. 6 illustrates a system in which the method of the present invention may be implemented.

SUMMARY

- The present invention is a method, apparatus and system to simultaneously determine the CP length and the cell group during the cell search step of detecting the frame timing and cell group using the S-SyS in a wireless telecommunications system.

DETAILED DESCRIPTION

 The present invention is a method to simultaneously determine the CP length and the cell group during the cell search when detecting the frame timing and cell group using

the S-SyS by time adjusting the Fast Fourier Transform (FFT) window for the S-SyS. The present invention further includes an apparatus and system adapted to implement said method.

When the P-SyS 5 ms timing is detected, the timing for S-SyS can be computed for both for the long CP and short CP length case, that is, the placement of the FFT window for both cases can be determined. In the present invention, the FFT window for S-SyS is set between the estimated timing for the long CP and short CP. Then, the channel in the frequency domain is positive phase shifted for the long CP length and negative phase shifted for the short CP relative the channel determined by the P-SyS. Therefore, prior to the correlation to the S-SyS sequences, the received frequency domain transformed S-SyS signal is positive and negative phase corrected and the S-SyS sequences are correlated to both corrected signals. The SyS sequence and correction giving maximum energy is detected as the cell group and the length of CP. As noted, the CP can be detected in the frequency domain, avoiding the multiple peak problem of the conventional method, while advantageously using only one FFT processing. Hence the method of the present invention is robust and has low complexity.

In Figure 3, the SyS timing relationships for the long CP and short CP are shown in more detail, together with an illustration of the S-SyS FFT timing 305 used in the present invention. As noted, first the apparatus correlates the P-SyS signals to the received signal in order to find the P-SyS sequence as well as P-SyS signal timing (providing 5 ms timing information). Ideally, the time instant 301 is detected, however due to, *inter alia*, noise, the correct timing might not be found, e.g., a chip could differ. Nevertheless, it is assumed that perfect timing is determined. The apparatus does not know if the cell has a long CP or short CP, hence either of the cases 302 or 303 is possible. The apparatus does have knowledge of the correct timing, subject to determination of there being a long CP 302 or short CP 303. Hence, in principal, the apparatus could set an FFT window on both places, perform two FFT operations and then perform the S-SyS detection to find the best match. However, such an operation requires two FFT operations, whereas the present invention only requires one FFT operation. As noted, the present invention is adapted to have an FFT time instant in between 302 and 303, shown in Figure 3 as 304. The timing position is preferably chosen in the middle between 302 and 303 so as to introduce equal phase shift for the two cases, but the present invention is not limited to that case. A further

embodiment of the present invention is to place the window based on the probabilities of short and long CP. If the probability is larger for a shorter CP the FFT-window is placed more to the right and vice versa. The benefit of this is less noise is introduced due to ISI for the most probable CP length when performing the S-SyS detection. One way to determine
 5 the probability is based on the CP length of the NB cells.

As is known from FFT processing of OFDM symbols, a sampling error of -n chips (relative ideal timing) gives a rotation of $-2\pi n/N_{FFT}$ radians between consecutive sub-carriers, where N_{FFT} is the length of the FFT. The foregoing relationship is true as long as the sampling error is within the CP, and therefore, if n is known it can be perfectly
 10 compensated for in the detection process. As can be seen in Figure 3, the FFT time instant 304 is outside the CP in both the long CP and short CP case, hence inter symbol interference (ISI) is introduced. The sampling time 304 introduces a sampling error in the order of 5-10% of the OFDM symbol length and such sampling error introduces distortion in the order of 7 to 8 dB signal to distortion ratio (SDR). However, the cell search is designed
 15 for detection in the range of a signal to noise ratio (SNR) of -6 to 0 dB, i.e., scenarios where the noise is stronger than the signal. Hence, the SDR introduced due to ISI is a magnitude smaller than the SNR for a typical cell search scenario and therefore, this ISI only contributes a negligible part of the noise power.

Assume sampling at time instant 304 results in a $\pm n$ chip sampling error to the ideal
 20 timing in the long CP (+) and short CP (-) case. A mathematical model of the frequency domain received S-SyS symbol at sub-carrier k (where N_{used} sub-carriers are used for S-SyS sequences) can now be written:

$$Y_k^{S-SyS} = e^{\pm j 2\pi \cdot n \cdot k / N_{FFT}} H_k s_k + e_k + \varepsilon_k^{ISI}, k = 1, \dots, N_{used} \quad (1)$$

25 where + is true if it is a long CP (positive), and - is true if it is a short CP (negative). The channel H_i is estimated using the P-SyS as a phase reference and hence can be equalized, i.e. can determine the CP length as well as the cell group of the received S-SyS. Equalization can be accomplished using a variety of techniques. For example, and without limitation, the following steps can be used to perform the equalization:

$$\tilde{Y}_k^{S-SyS} = \frac{Y_k^{S-SyS}}{\hat{H}_k} \approx e^{\pm j 2 \pi \cdot n \cdot k / N_{FFT}} s_k + \tilde{e}_k \quad (2)$$

Now, two de-rotated versions, each version phase corrected with the phase shift corresponding to the long CP and short CP of the received S-SyS are generated and the two phase corrected versions are correlated to all possible M S-SyS sequences and the correlation giving the highest power is used to determine the CP length as well as the cell group. Mathematically speaking, the following steps are performed:

$$\tilde{Y}_k^{long CP} = e^{-j 2 \pi \cdot n \cdot k / N_{FFT}} \tilde{Y}_k^{S-SyS} \quad (3)$$

$$\tilde{Y}_k^{short CP} = e^{j 2 \pi \cdot n \cdot k / N_{FFT}} \tilde{Y}_k^{S-SyS} \quad (4)$$

cell group, CP length =

$$\arg \max_{(long/short), m} \left| \sum_{k=1}^{N_{used}} (s_k^m) \bullet [\tilde{Y}_k^{long CP}, \tilde{Y}_k^{short CP}] \right|^2$$

$$m = 1 \dots M \quad (5)$$

A flowchart 400 illustrating the method of the present invention is provided in Figure 4. As seen therein, in step 401, the P-SyS timing τ is determined using the P-SyS, which corresponds to 301 of Figure 3. In step 402, the S-SyS timing is determined, corresponding

to 304 of Figure 3. In step 403, the FFT window is placed and the signal is FFT processed to obtain the frequency domain S-SyS symbols. In step 404, the frequency domain S-SyS signal is equalized, for example in accordance with equation (2), and then phase corrected according to equations (3) and (4). In step 405, the cell group and CP length detected are
5 given by the correlation giving maximum energy according to equation (5).

An apparatus adapted to implement the method of the present invention is provided in Figure 5. Figure 5 is a high-level block diagram 500 of an apparatus of the present invention, comprising an antenna 501, front end receiver (Fe RX) 502, analog to digital converter (ADC) 503, P-SyS correlation module 504, S-SyS timing module 505, Fast
10 Fourier Transform module 506, Phase correction module 507, channel estimation module 508, detector 509 and S-SyS detector 510. As seen therein, the apparatus, which may include a UE, is adapted to perform the following operations:

After signal is received at antenna 501 and demodulated at FE RX 502 it is converted into a digital signal at ADC 503. The P-SyS timing τ is determined using the P-SyS, which corresponds to 301 of Figure 3, at P-SYS correlation module 504.
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The S-SyS timing is derived at S-SyS timing module 505, based on outcome from P-SyS, corresponding to 304 of Figure 3. The FFT window is placed and the signal is FFT processed to obtain the frequency domain S-SyS symbols at FFT module 506. The frequency domain S-SyS signal is equalized, for example, in accordance with equation (2)
20 and then phase corrected according to equations (3) and (4). The cell group and CP length detected are given by the correlation giving maximum energy according to equation (5) in S-SyS detector module 510. In channel estimation unit 508, the channel H is estimated. For S-SyS detection, the f-domain representation of the P-SyS is used as pilots for the channel estimation used for S-SyS equalization. Furthermore the reference symbols
25 (pilots) are used to obtain the channel estimate used for data equalization and detection in detector 509.

Figure 6 illustrates a wireless network 600 in which an apparatus according to the principles of the present invention may be used. Wireless network 600 comprises a plurality of cell sites 601A...601N each containing a base station (BS) adapted to communicate with
30 apparatus 602. Apparatus 602 may be any suitable wireless devices, including a UE, cellular radiotelephones, handset devices, personal digital assistants, portable computers,

or metering devices. The present invention is not limited to mobile handsets. Other types of access terminals, including fixed wireless terminals, may be used. However, for the sake of simplicity, only UEs are shown and discussed herein.

5 Dotted lines 603 show the approximate boundaries of the cell sites 601. The cell sites are shown approximately circular for the purposes of illustration and explanation only. It should be clearly understood that the cell sites often have other irregular shapes, depending on the cell configuration selected and natural and man-made obstructions.

As is well known in the art, cell sites 601 are comprised of a plurality of sectors (not shown), each sector being illuminated by a directional antenna coupled to the base station.
10 The embodiment of Figure 6 illustrates the base station in the center of the cell. Alternate embodiments position the directional antennas in corners of the sectors. The system of the present invention is not limited to any particular cell site configuration.

In the wireless network 600, apparatus 602 is located in cell sites 601A, 601B and is in communication with serving cell 601B. Apparatus 602 is also located close to the edge of
15 cell site 601B. Apparatus 602 routinely performs cell searches to detect the base stations of a wireless network in the vicinity of the apparatus 602. Whenever an apparatus is turned on, an initial cell search is performed in order to search for and acquire at least one of the base stations of wireless network. Thereafter, the apparatus continues to perform cell searches in order to determine the strongest base station(s) in the vicinity and to identify
20 available base stations to which the mobile station may be transferred in case it is necessary to perform a handoff. To improve the efficiency of these cell searches, the system of the present invention includes the apparatus of Figure 5 in combination with wireless network.

There have been described and illustrated herein methods, apparatus, and systems
25 to simultaneously determine the CP length and the cell group during the cell search by time adjusting the Fast Fourier Transform (FFT) window for the S-SyS. While particular embodiments of the present invention have been described, it is not intended that the present invention be limited thereto, as it is intended that the invention be as broad in scope as the art will allow and that the specification be read likewise. For example, the
30 method can be used where there are more than two CP length hypotheses present. In such case, the phase de-rotation is proportional to the difference between the used sampling time instant and the ideal sampling instant for each respective CP length hypothesis. Then

the steps described herein can be applied. Further, while the apparatus of the invention is shown in block diagram format, it will be appreciated that the block diagram may be representative of and implemented by hardware, software, firmware, or any combination thereof. Moreover, the functionality of certain aspects of the block diagram can be obtained

5 by equivalent or suitable structure. For example, instead of an FFT, other Fourier transform means could be utilized. It will therefore be appreciated by those skilled in the art that yet other modifications could be made to the provided invention without deviating from its spirit and scope as claimed.

CLAIMS

1. A method for simultaneous cell group and cyclic prefix (CP) detection, comprising the step of placing a single Fast Fourier Transform (FFT) window for a secondary synchronization signal (S-SyS) between the estimated timing corresponding to an Orthogonal Frequency Division Multiplex (OFDM) symbol transmitted using a long CP or a short CP.

2. A method for simultaneous cell group and cyclic prefix (CP) detection, comprising the steps of:

placing a single Fast Fourier Transform (FFT) window for a secondary synchronization signal (S-SyS) between the estimated timing for a long CP and a short CP;

performing a first phase shift of the channel in the frequency domain for the long CP length;

performing a second phase shift of the channel in the frequency domain for the short CP relative the channel determined by a primary synchronization signal (P-SyS);

phase correcting the received frequency domain transformed S-SyS signal prior to the correlation to the S-SyS sequences;

correlating the S-SyS sequences to both corrected signals;

detecting the S-SyS sequence and correction providing maximum energy as the cell group and the length of CP.

3. The method of claim 2, wherein the timing position is in the middle between the long CP and short CP.

4. The method of Claim 2, wherein the first phase shift is a positive phase shift and the second phase shift is a negative phase shift.

5. The method of claim 2, for use in a user equipment (UE).

6. A method for detecting simultaneous cell group and cyclic prefix (CP), comprising the steps of:

determining primary synchronization signal (P-SyS) timing τ using the P-SyS;

based on τ , determine a secondary synchronization signal (S-SyS) timing;

positioning a single Fast Fourier Transform (FFT) window;
 FFT processing the signal to obtain the frequency domain S-SyS symbols;
 equalizing the frequency domain S-SyS signal;
 phase correcting the signal; and
 detecting the cell group and CP length by the correlation giving maximum energy.

7. The method of Claim 6, wherein the equalizing step is in accordance with:

$$\overline{Y}_k^{S-SyS} = \frac{Y_k^{S-SyS}}{\hat{H}_k} \approx e^{\pm j 2\pi \cdot n \cdot k / NFFT} S_k + e_k$$

8. The method of Claim 6, wherein the phase correcting step is in accordance with the formulas:

$$\tilde{Y}_k^{long CP} = e^{-j 2\pi \cdot n \cdot k / NFFT} \tilde{Y}_k^{S-SyS}$$

$$\tilde{Y}_k^{short CP} = e^{j 2\pi \cdot n \cdot k / NFFT} \tilde{Y}_k^{S-SyS}$$

9. The method of Claim 6, wherein the correlation providing maximum energy is based on the following formula:

cell group, CP length =

$$\arg \max_{(long / short), m} \left| \sum_{k=1}^{N_{used}} (s_k^m) \bullet [\tilde{Y}_k^{long\ CP}, \tilde{Y}_k^{short\ CP}] \right|^2$$

$$m = 1 \dots M$$

10. The method of Claim 6, for use in a user equipment (UE).

11. A method for simultaneous cell group and cyclic prefix (CP) detection, comprising the steps of:

- determining a primary synchronization signal (P-SyS) timing;
- based on the timing, determining secondary synchronization signal (S-SyS) timing;
- placing a single Fast Fourier Transform (FFT) window;
- performing a FFT;
- obtaining S-SyS symbols;
- testing the S-SyS sequences to phase corrected S-SyS symbols; and
- obtaining the cell group and CP length based on the best S-SyS correlation match.

12. The method of Claim 11, wherein the best S-SyS correlation is based on the correlation providing maximum energy according to the following formula:

cell group, CP length =

$$\arg \max_{(long / short), m} \left| \sum_{k=1}^{N_{used}} (s_k^m) \bullet [\tilde{Y}_k^{long\ CP}, \tilde{Y}_k^{short\ CP}] \right|^2$$

$$m = 1 \dots M$$

13. The method of Claim 6, for use in a user equipment (UE).

14. An apparatus for simultaneous cell group and cyclic prefix (CP) detection, comprising:

cell search means for determining primary synchronization signal (P-SyS) timing;

cell search means for determining secondary synchronization signal (S-SyS) timing based on the P-SyS timing;

means for placing a single Fast Fourier Transform (FFT) window;

means for performing a FFT;

means for obtaining a plurality of S-SyS symbols;

means for testing the S-SyS sequences to phase corrected S-SyS symbols; and

means for obtaining the cell group and CP length based on the best S-SyS correlation match.

15. The apparatus of Claim 14, in combination with a UE.

16. The apparatus of Claim 11, wherein the UE comprises:

an antenna;

a front end receiver (Fe RX) having an input coupled to the antenna;

an analog to digital converter (ADC) having an input coupled to the output of the Fe RX;

a P-SyS correlation module having an input coupled to the output of the ADC;

a S-SyS timing module having an input coupled to the output of the P-SyS correlation module;

a Fast Fourier Transform (FFT) module having an input coupled to the output of the ADC and an input coupled to the output of the P-SyS module and S-SyS timing module;

a phase correction module having an input coupled to the output of the P-SyS correlation module;

a channel estimation module having an input coupled to the output of the FFT;

a detector module having an input coupled to the output of the FFT and the output of channel estimation module;

a S-SyS detector having an input coupled to the output of the phase correction module and the output of the channel estimation module, wherein the P-SyS timing τ and S-SyS timing are determined using the P-SyS, at P-SyS correlation module, the FFT window is placed and the signal is FFT processed to obtain the frequency domain S-SyS symbols at FFT module and the cell group and CP length detected at S-SyS detector are given by the correlation giving maximum energy in S-Sys detector module.

17. The apparatus of claim 16, for use in an Orthogonal Frequency Division Multiplexing (OFDM) modulation system.

18. An Orthogonal Frequency Division Multiplexing (OFDM) modulation system, comprising:

a module for determining primary synchronization signal (P-SyS) timing τ using the P-SyS;

a module for determining a secondary synchronization signal (S-SyS) timing based on τ ;

a module for placing a Fast Fourier Transform (FFT) window;

a FFT module for processing the signal to obtain the frequency domain S-SyS symbols;

a module for equalizing the frequency domain S-SyS signal;

a module for phase correcting the signal; and

a module for detecting the cell group and CP length by the correlation giving maximum energy.

19. The system of Claim 18, in combination with a user equipment (UE) for use in a Long Term Evolution system.

20. The OFDM modulation system of Claim 18, wherein the correlation providing maximum energy is based on the following formula :

cell group, CP length =

$$\arg \max_{(long/short),m} \left| \sum_{k=1}^{N_{used}} (s_k^m) \bullet [\tilde{Y}_k^{long\ CP}, \tilde{Y}_k^{short\ CP}] \right|^2$$

$$m = 1 \dots M$$