The LTE Access Procedure

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***Abstract*—This paper describes the LTE access procedure with a main focus on the cell search procedures. The cell search is carried out by two synchronization signals i.e. the primary synchronization signal which is needed when a user equipment (UE) connects for the first time to a cell or is looking for a new one to make a cell handover, and secondary synchronization signal which is needed to provide the terminal with information about the cell ID, frame timing properties and the cyclic prefix (CP) length. The report goes through the different synchronization methods in the cell search discussing their advantages and disadvantages in synchronization. We propose an algorithm that aims for improving the cell search procedure in terms of lower complexity and increased detection probability while maintaining a robust connection.**

KEYWORDS: LTE, Access procedure, Cell search, Synchronization signals, Cell search algorithms

I. Introduction

The driving forces behind the evolution of 3G is that the carriers need to stay competitive by providing better services at lower cost. It is this competitiveness that drives the technology advancement. Since the fundamental goal of any mobile communication system is to deliver services to the end users, the engineers need to build systems that can adapt to the changing environment i.e. predict which services that could become popular in a period of five to ten years [1].

To be able to solve these challenges the third generation partnership project (3GPP) group came up with a standard consisting of two parts. One part is the high speed packet access (HSPA) Evolution which is built on existing specifications and can use already installed equipment that uses the 5 MHz spectrum. However, one drawback is that HSPA must be backward compatible with older terminals [1].

The other part is the long term evolution (LTE) which is based on orthogonal frequency-division multiple access (OFDMA) in down-link and single-carrier frequency-division multiple access (SC-FDMA) in up-link. It offers favorable features such as high spectral efficiency, robust performance in frequency selective channel conditions, simple receiver architecture and lower latencies [2]. It also uses the same spectrum bands as most of the other 3G technologies. In LTE there is the possibility to use new designs and LTE does not need to be backward compatible with the older terminals. This made it possible to design the radio interface to be completely based on packet-switched network technology and the designers did not need to care about the circuit-switched part [1].

All in all, the main reasons of developing LTE was to sustain packet switched traffic (IP traffic), voice traffic e.g. voice over IP. In addition it permits both frequency-division duplexing (FDD) and time-division duplexing (TDD) communication. Its support for multiple input multiple output (MIMO) technology gives it an advantage in the communication arena [3].

As a starting point, in LTE, before a terminal can start to use the network there must be some connection associated with the network and that is what is called the access procedure. This procedure consists of the following parts: finding and acquiring synchronization to a cell within the network, receive and decode the information (cell system information), request a connection setup (random access) and network-initiated connection setup (paging) [1].

The cell search in 3GPP LTE is complex and computationally expensive. It is also power and time consuming since it is computing correlation between transmitted and received signals. The fundamental issues in cell search synchronization are rotated on cell detection, complexity, channel fading and robustness. Although many algorithms are in place to solve the fore mentioned issues, still we have not found one that capture them at once hence making the cell search even more complex with even higher power consumption by applying different algorithms to solve the issue.

This research is focused on the cell search and synchronization with a main objective of increasing the detection probability of the cell ID and reducing complexity while maintaining robustness. In this, the report explains how the user equipment (UE) behaves depending on if it is an initial synchronization procedure or new cell identification. The different synchronization methods and algorithms are used as a basis for a proposed algorithm for cell search synchronization. This algorithm tries to increase detection probability, reduce complexity, and handle channel fading yet leaving the access procedure robust and yet in a single algorithm.

Together with this introduction, the paper is organized as follows; section II describes the general view of the access procedure steps i.e. the cell search, the system information, the random access and paging. Section III covers the different, already existing cell search algorithms, Section IV covers the proposed algorithm, and section V covers the conclusion of the paper.

II. Access Procedure

Before the user equipment can start transmitting and receiving data it must connect to the network. This connection phase consists of 3 stages where different information is obtained in each stage. In this section we give an over view of the cell search procedure stages which is the main concern of this paper. That is, the cell search with the different types of cell search procedures, the synchronization signals, the structure of those signals and how to detect the signals. The other stages of the access procedure will also be explained i.e. the derivation of system information, the random access and the paging.

A. The Cell Search

The first thing that happens in the access procedure is that the UE must be identified within the network. This procedure is called the cell search and includes synchronization between UE and the cell and acquiring the information about cell [1]. The synchronization procedures which are mentioned later are performed in order to obtain timing synchronization for correct symbol detection. It is also used for frequency synchronization to annihilate frequency mismatches caused by moving of UE or different oscillators at the receiving and transmitting sides. Moreover it is needed to obtain cell ID as it is described later [4]. Section 1 covers the different types of cell search procedures, section 2 covers the synchronization signals, section 3 covers the structure of those synchronization signals and section 4 covers how the detection is done for the signals.

1) Cell Search Procedures: There are two different types of synchronization procedures. The first one is when the UE is not connected to LTE cell and wants to access LTE network. This happens when the UE is switched on or when the reception is restored after being in an area with no connection. The second type of synchronization procedure happens when the UE is already connected to LTE cell and detects a new cell. This means the UE will prepare for a handover to a new cell and will report this to the old cell. This behavior is repeated until the reception is satisfactory as long as there are new cells available. Both these procedures use two types of synchronization signals, that is the primary synchronization signal (PSS) and the secondary synchronization signal (SSS) which are broadcasted in each cell. For the initial synchronization the UE is also required to decode physical broadcast channel (PBCH). The PSS and SSS provide the UE with its physical layer identity within the cell. There are 504 possible physical layer cell identities, to obtain cell ID hierarchical scheme is applied according to which all physical layers are divided into tree groups of physical layer identities where each contains 168 cell layer identities. The signals also provide frequency and time synchronization within the cell [4]. What is obtained from the synchronization signals can be seen in in Fig.1.

2) Synchronization Signals: Since OFDM systems are sensitive to time and frequency synchronization errors, there is a need to have synchronization, power control and random access [3]. As in [3], primary synchronization is required when a mobile terminal connects to a cell for the first time

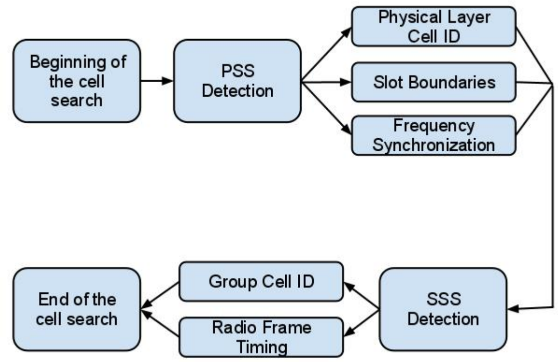

Fig. 1. Cell search and Synchronization Signals

or is searching for a new one to perform a cell handover. Primary synchronization detects the base station (eNodeB) sector and time offset [3]. The PSS is constructed from signal sequences that are known as Zadoff-Chu (ZC) sequences and the length of the sequence is 62 in the frequency domain [4]. These sequences are used because they provide good detection probability at the same time they provide low false alarm rate which is very useful in LTE. The Zadoff-Chu sequences belong to a class of complex exponential sequences and is a type of waveform that is called constant amplitude zero auto-correlation sequences (CAZAC) [14]. When a terminal detects a PSS it can then extract information about slot timing properties and the ID of the physical layer [4].

The SSS on the other hand uses two interleaved sequences that are called maximum length sequences (MLS), SRG-sequences or m-sequences which are of length 31. They are scrambled with PSS sequences that determine physical layer ID. The m-sequence is defined as the longest sequences possible to generate using a shift register. The m-sequence is a binary sequence and the next value is linearly dependent on k sequences of preceding values that are calculated using the same method [5].

The purpose of the SSS is to provide the terminal with information about the cell ID, frame timing properties and the cyclic prefix (CP) length. The terminal is also informed whether to use TDD or FDD [4].

3) Structure of PSS and SSS: Each OFDM unit is 10ms long. Each unit is divided into 10 subframes of 1 ms, subframes are also splitted into 0,5ms slots. Such slot can contain seven OFDM symbols with normal CP length and six with extended CP . In FDD cells PSS is located in the last OFDM symbol in first and eleventh slot of the frame, SSS follows it in the next symbol. In TDD cell PSS is sent in the third symbol of the 3rd and 13th slots while SSS is transmitted three symbols earlier as in the Fig. 2. PSS gives UE information about to which of the three groups of physical layers the cell belogs to (3 groups of 168 physical layers). One of 168 SSS sequences is decoded right after PSS and defines the cell group identity directly [4].

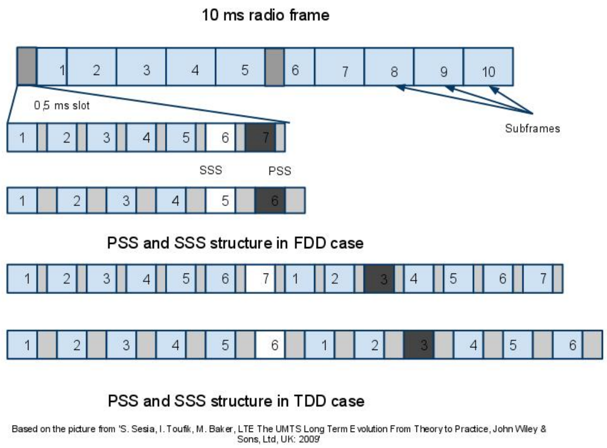

Fig. 2. The Structure the PSS and SSS

4) Coherent and Non-Coherent Detection: Coherent detection is based on detecting sequence that maximizes the probability of transmitting the sequence taking already known information about the channel. To be able to use coherent detection a channel estimation needs to be done before the sequence detection can start [4].

In the case where the channel estimation cannot be done and any other knowledge about the channel exists, non-coherent detection can be used. This is done by removing the dependency that exists for a given channel and compute the average of the distribution of the random channel coefficients [4]. For both the coherent and non-coherent maximum likelihood (ML) approach is implemented as in equations as seen in 7.8 and 7.14 in [4]).

Both these detection methods are important for the synchronization procedures. For the existing implementation of LTE, a non-coherent approach is used for the PSS and both a coherent or non-coherent approach can be used for the SSS.

B. Deriving System Information, Random Access and Paging

The second part of the access procedure is where the UE needs to derive system information. This system information is periodically broadcasted in the network and this information is needed for the UE to be able to connect to the network and a specific cell within that network. When the UE has received and decoded the system information it has information about for example cell bandwidths, whether to use FDD or TDD and enough information to be able to access the cell via the random-access procedure [1].

The third and fourth stage is the random access and the paging. The random access is when the UE requests a connection setup. That is used for initial synchronization or when the UEs serving cell needs to handover the UE to another cell among other purposes. The paging on the other hand is used for network initiated connection setup [1]. The system information, random access and the paging is not covered more deeply in this project. For detailed information about these procedures refer to [1].

III. Synchronization methods and algorithms

Synchronization is relevant when it comes to the context of wireless communication, however there are some problems associated to it. There are many attempts to simplify and improve synchronization algorithms in the LTE cell search. Some of the latest suggestions have been observed below.

In [3], they present two robust algorithms for primary Synchronization method which rely on the traditional methods based on cross-correlation properties of Zadoff-Chu sequences [1], [6], [7], [8], [9] and [13]. This is presented with a main focus of increasing the probability of detection at lower signal to noise ratios because the possibility to realize synchronization in harsh environment is also of utmost importance. The two proposed algorithms in [3], provide extra robustness through a validation process proposed to be soft or hard. The soft validation increases the detection probability of the cell ID and the hard validation although easy to implement, has got a lower performance. Their result contain the value for the sector identifier and location of the primary sequence which is necessary for further synchronization and confirmation through the cell specific reference (RS) [3].

Similarly to [3], Ni et al. [10], they also propose a complexity effective cell search scheme based on the combination of the coherent sequence detection and sign decision. In their paper, integrating the sector ID detection and cell group ID detection in the Secondary Synchronization Channel, and using the primary Synchronization Channel as a phase reference, their complexity effective cell search scheme "can overcome the adverse effect of channel fading and frequency offset" with low complexity at the cost of robustness.

The cell search in 3GPP LTE is complex and computationally expensive and power and time consuming since it is computing correlation between transmitted and received signal. One of the proposed method to decrease the complexity of the cell ID acquisition was based on the developing a perfect sequence with a special structure for this procedure. Proposed primary and secondary synchronization signals are described in details in [11]. As a result the number of complex multiplications and complex additions has decreased from 336No to 5 No and 336(No-1) to 30(No/8) respectively, where No is the length of the sequence.

Also as described in [12], the Ericsson/Lund university team has come up with a novel, low complexity cell search algorithm. The aim of this algorithm is to make the implementation robust in the sense that it should tolerate doppler spread and handle sample time mismatches that result in phase shifting. To be able to do that they used a non-coherent approach that is useful both in synchronized LTE TDD and high speeding scenarios. The results that they came up with showed that the non-coherent approach gained much better performance and was more robust against doppler spreads and phase shifting [12].

In all the algorithms seen, each of them has got some issues it address for the cell search and some short comings. So the trade off can be at the expense of some qualities. As in [3], robustness and probability detection are addressed where as the complexity issue is not solved. In [10], complexity and detection are addressed but not robustness and similarly in [12], robustness and complexity are the issue solved and less focus on the detection probability. In this, it mean in order to have a robust connection with low complexity and yet with a high probability detection there is a need to combine each of the advantages in one algorithm other than using them different since this can result in yet another complex solution.

IV. Proposed Detection Method

The profound search of new algorithms for the cell search showed that most of them are looking for a accurate detector of the PSS and SSS. The detection of the PSS is dome usually in a traditional way using non-coherent method without using any prior information about the channel. thus slot boundaries are found and the channel estimation is done to detect SSS further.

In TDD cells, coherent detection of SSS may be inaccurate due to the following problems; According to the structure of the 10 ms radioframe and the location of synchronization signals in the time domain cells PSS and SSS are separated by two OFDM symbols. Therefore if the object is moving with a high speed the channel can vary from symbol to symbol, the same happens in the conditions of fading channel or a phase shift caused by the sample time mismatch. Non-coherent detection provides the better detection of SSS in those conditions but is done with higher complexity and requires longer operation time compared to coherent approach [4], [6], [16].

According to the traditional scheme for SSS detection the received signal is correlated with all possible sequences and after applying ML detector the timing is obtained.

Practically the number of multiplications and additions in this procedure is quite large [11], thus the whole system is beneficial in terms of correct detection of all synchronization signals but is also needed to be simplified.

To decrease the computational costs, the new sequence for SSS is proposed to be applied for this algorithm.The sequence is based on the Gaussian integer perfect sequence (GIPS) of length 16N. The sequence was clearly described in [11]. Non-coherent detection is based on differential correlation that replaces the effect of that channel to the signal. The detection process can be seen in Fig.3. The SSS detection is done in the frequency domain therefore FFT is applied to the sequence. After deinterleaving and descrambling the decision devise is detecting a cell ID [15] as in equations (1) and (2).

$$\hat{m_0} = \arg\max_i \left| \sum_{l=1}^{30} \beta_{m_0}[l]\beta^*_{m_0}[l-1]s^{(i)}[l]s^{*(i)}[l-1] \right|^2 \quad (1)$$

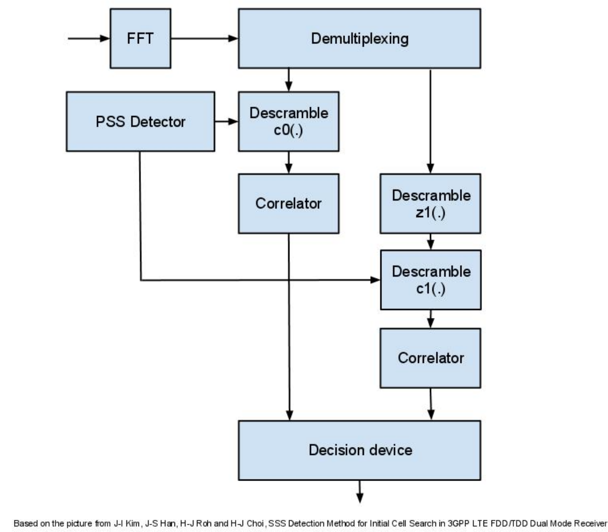

Fig. 3. The Structure of Non-Coherent SSS Detection

$$\hat{m_1} = \arg\max_i \left| \sum_{l=1}^{30} \beta_{m_1}[l]\beta^*_{m_1}[l-1]s^{(i)}[l]s^{*(i)}[l-1] \right|^2 \quad (2)$$

Where $\beta_{m_0}[l]$ and $\beta_{m_1}[l]$ are the descrambled SSS sequences at the receiver and $s(i)[l]$ is the SSS sequences itself (based on eq. 10 and 11 in [15]).

Combined effective non-coherent detection in TDD cells with perfect sequence helps to escape from complexity of the system. The sequence results in the decreasing of the complexity in times while maintaining the detection probability and robustness against channel effects. Though the detection may fail with low SNR levels.

V. Conclusion

In this article, we have studied the cell search procedure in 3GPP LTE system. The main focus has been put on cell search and synchronization. The two synchronaization signals used in the cell search have been presented i.e. the primary synchronization and secondary synchronization signals. where the primary synchronization signal is needed when a user equipment (UE) connects for the first time to a cell or is looking to make a cell handover, and secondary synchronization signal is needed to provide the terminal with information about the cell ID, frame timing properties and the cyclic prefix (CP) length. Different algorithms have been discussed for enhancing mobility, reliability and robustness in the cell search which aim at handling channel fading, frequency offset, doppler spread and phase shifting.The presented algorithms either improve the probability of the cell ID detection, reduce complexity or give a robust connection. Non of the algorithm however, can enhance all the qualities. This article however has proposed a theoretical base of an algorithm based on the discussed algorithms which tries to handle all the qualities in one. The algorithm is based on the low complex perfect sequence for SSS and applying non-coherent detection with differential correlation to obtain cell ID. This then makes the algorithm to be protected from the inaccurate results due to Doppler spread, phase shifts of any other channel impact. However one weakness of the algorithm may be in implementing the search procedure when SNR is approximately -4dB or lower. It is important to note however, that the proposed algorithm is proposed theoretically hence need for future research to include its implementation.

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VI. Review question for the final exam

What is the 3 first steps that are performed in the access procedure before the user equipment can start using the network? Answer: First step: Cell search and synchronization Second step: Deriving System Information Third step: Random access