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Analysis of the impact of PCI planning on downlink throughput performance in LTE

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ABSTRACT

The planning of Physical Cell Identities (PCI) has a strong impact on the performance of Long Term Evolution cellular networks. Although several PCI planning schemes have been proposed in the literature, no study has quantified the performance gains obtained by these schemes. In this paper, a comprehensive performance analysis is carried out to quantify the impact of PCI planning on user quality of service and network capacity in the downlink of LTE. First, an analytical model for the influence of PCI planning on reference signal collisions is developed. Based on this model, different PCI planning schemes are tested on a dynamic system-level simulator implementing a macrocellular scenario. During the analysis, both Voice-over-IP and full buffer services over time-synchronized and non-time synchronized networks are considered. Results show that call blocking and dropping for real-time services and user throughput for non-real time services can be significantly improved by a proper PCI plan.

1. Introduction

The size and complexity of current mobile networks make it very difficult for operators to manage them. Thus, a huge effort has been made by standardization bodies and vendors to define and develop automatic network operation features [1]. As a result, the Long Term Evolution (LTE) mobile communication standard includes Self-Organizing Networks (SON) capabilities [2,3]. SON features aim to perform planning, optimization and healing tasks with minimal human intervention.

Physical Cell Identifier (PCI) planning in LTE has been identified as an important use case for self-planning [4,5]. A PCI (or Layer 1 identity) is a signature assigned during network planning to identify a base station in mobility functions, such as cell reselection or handover [6]. The number of PCIs is limited, which forces several base stations (or eNodeBs, eNBs) to share the same PCI. As a result, a wrong assignment of PCIs may cause that a user receives the same PCI from two different cells (problem referred to as *collision*) or a serving cell has two neighbors with the same PCI (referred to as *confusion*) [2]. Both situations prevent users from detecting cells, causing that no radio communication is possible.

At the same time, PCI defines the location in time and frequency of signaling channels, amongst which are downlink Cell-Specific Reference Signals (CRS). In the time domain, CRSs (or pilots) are transmitted in the same OFDM symbol of the frame structure in all cells. However, in the frequency domain, each cell transmits CRSs in different subcarriers depending on the value of its PCI. Thus, each cell has a specific pilot pattern corresponding to its cell identity. The number of possible pilot patterns depends on the antenna configuration, but it is always less than 6

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[7], causing that CRSs of surrounding cells often collide. CRS collisions degrade Signal-to-Interference-plus-Noise Ratio (SINR) estimates, reported by the User Equipment (UE) and later used by the eNB to select the modulation and coding scheme (MCS) for downlink transmission. Thus, an improper PCI planning may give inaccurate SINR estimates, which leads to inefficient data transmission in the downlink [8].

In the literature, most research efforts on PCI planning have focused on the avoidance of collision and confusion. For this purpose, PCI planning is formulated as a graph coloring problem, which can be solved by graph-theoretic algorithms [9–11] or general-purpose optimization algorithms (e.g., genetic algorithms [12]). Preliminary studies considered centralized schemes [13] and later studies evaluate distributed versions [14,15]. Both types of schemes are considered by 3GPP for LTE [16]. Distributed PCI assignment is conceived for self-configuring eNBs to support plug-and-play operation. In this approach, a centralized entity provides a list of possible PCI values, which is then restricted by the eNB by removing those reported by terminals or by neighbor eNBs through the X2 interface [17]. Alternatively, the centralized solution is based on a central entity that stores location and PCI assignment of all eNBs in the network [18]. Thus, a collision and confusion free assignment is guaranteed at the expense of an increased computational complexity, which makes it suitable only for greenfield design or infrequent re-planning processes. In [19], a decentralized method for detecting PCI conflicts based on user measurements is proposed. Recent works have extended the analysis of PCI planning to heterogeneous LTE networks, consisting of several layers, by considering collision and confusion between cells of different layers [20–25]. Other studies (e.g., [26]) propose optimal CRS allocation patterns in the time and frequency domains. However, these schemes do not consider CRS collisions between neighbor cells nor they are compliant with LTE standard. In [27], a heuristic PCI planning algorithm is proposed to keep PCI reuse distance within certain limits while still avoiding CRS collisions in sectors of the same site. However, although LTE network performance has been well documented (e.g., in [28,29]), to the authors' knowledge, no study has quantified the impact of PCI planning on downlink data transmission due to pilot collisions on a system level. In this work, a performance analysis is carried out to check the impact of classical PCI planning schemes on user quality of service and network capacity in the downlink of LTE. The core of the analysis is the modeling of the influence of PCI planning on CRS collisions. The proposed model is included in a dynamic system-level simulator implementing both VoIP and full buffer services, with time-synchronized and non-time synchronized schemes, in a macrocellular scenario.

The main contributions of this work are: (a) a simple interference model to evaluate the impact of PCI planning on LTE downlink performance, and (b) simulation results showing how much is network capacity and user throughput influenced by PCI planning for different services. The rest of the paper is organized as follows. Section 2 formulates the PCI planning problem explaining how PCI planning determines CRS collisions. Then, Section 3 outlines classical PCI planning schemes proposed in the literature, for which a downlink interference model is developed in Section 4. Section 5 presents the results of simulations carried out to assess the PCI planning approaches. Finally, Section 6 presents the concluding remarks.

2. Problem formulation

Cell search is the first process executed by a user connecting to an LTE network. This process requires the synchronization of the radio symbols and frame user timing with that of the eNB. For this purpose, two synchronization signals are used, namely the *Primary Synchronization Signal* (PSS) and the *Secondary Synchronization Signal* (SSS), broadcasted by the eNB every 10 ms [30]. PSS is used to detect the carrier frequency and the SCH (Shared Channel) symbol timing, while SSS is used to align frame timing by identifying slots within the frame. Detection of these signals not only enables synchronization, but also allows the user to obtain the PCI of the cell.

Fig. 1 shows the structure of PSS and SS frame in the time domain in the frequency division duplex (FDD) case. During cell search, the UE first finds the PSS, which is located in the last OFDM symbol of the first time slot in

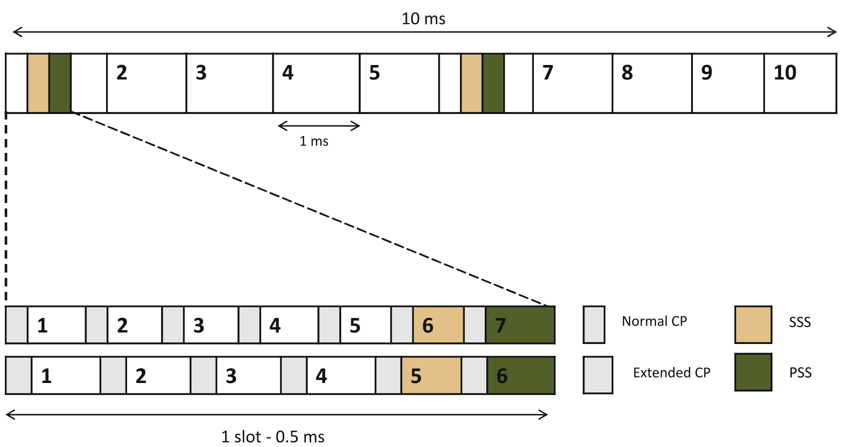

Fig. 1. PSS and SSS frame and slot structure in the time domain in FDD case.