Chapter 2
Aperiodic ICIC–Oriented CSI Reporting for LTE Networks

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ABSTRACT
Interference mitigation has been identified as an important challenge for cellular technologies based on Orthogonal Frequency Division Multiple Access (OFDMA) such as the Long Term Evolution (LTE) system of the Third Generation Partnership Project (3GPP). In this context, Intercell Interference Coordination (ICIC) techniques have received much attention by the research community, as they are a good approach to address this issue. In particular, static solutions enjoy acceptance due to their low complexity and ease of implementation. ICIC mechanisms are not standardized in LTE, which just provides certain support so that every vendor/operator configures its particular ICIC option. Hence, their interworking with other important network functionalities such as Channel State Information (CSI) feedback must be carefully considered. This chapter provides an overview on the relationship between ICIC and CSI in LTE and introduces a novel mechanism to improve such interworking. The novel scheme is feasible and easy-to-implement and it is especially effective for Non-Real Time services. It provides gains in terms of system capacity, cell edge performance, and energy efficiency with respect to 3GPP LTE mechanisms and previous proposals.

I. INTRODUCTION
In the context of modern cellular networks, the demand for new and attractive packet-based services is currently growing faster than ever. Services and applications are increasingly requiring higher levels of Quality of Service (QoS). In this context, the Long Term Evolution (LTE) of the 3rd Generation Partnership Project (3GPP) is foreseen to be a leading system towards the fourth generation (4G). Indeed, LTE-Advanced (LTE release 10) is the 3GPP solution for 4G mobile broadband and was approved by the International Telecommunications Union (ITU) as an Interna-
Aperiodic ICIC-Oriented CSI Reporting for LTE Networks

International Mobile Telecommunications-Advanced (IMT-A) technology in late 2010.

LTE features a packet-optimized Radio Access Technology (RAT) and flat all-IP architecture allowing a reduced number of network elements. It also features flexible bandwidth allocation based on Orthogonal Frequency Division Multiple Access (OFDMA) in the downlink. OFDMA implies intrinsic orthogonality among users in a cell, and so, it provides nearly null intracell interference. However, with a low frequency reuse factor (ideally 1), intercell interference becomes a major concern as users get close to cell edge. Under these circumstances, the QoS remarkably depends on the user position, which yields to the concept of fairness.

In the light of this situation, Intercell Interference Coordination (ICIC) has been recognized as a fundamental piece of OFDMA based cellular technologies (Himayat, Talwar, Rao, & Soni, 2010). Broadly speaking, the main target of any ICIC strategy is to determine what resources (bandwidth and power) are available at each cell at any time in order to reduce interference levels and improve fairness among users. Considering the temporality in which resource coordination is performed it is possible to distinguish between static or dynamic ICIC. In particular, static ICIC currently holds certain popularity because of its ease of implementation and distributed operation, being Soft and Fractional Frequency Reuse (SFR and FFR,) the techniques par excellence. The reader is referred to (González G, García-Lozano, Ruiz, & Olmos, On the Need for Dynamic Downlink Intercell Interference Coordination for Realistic LTE Deployments, 2012) for a complete review of the state-of-the-art on ICIC. It is worth saying that LTE specifications do not standardize this important functionality, in turn, only certain mechanisms and enablers of potential ICIC strategies are provided.

Whereas ICIC is in charge of determining resources to be used in each cell and groups of users in the mid and long term, scheduling deals with resource allocation at the very short term scale. In this sense, Channel State Information (CSI) feedback is a key functionality whose role is of utmost importance. Updated and free of errors CSI allows taking opportunistic decisions, and thus, making the most of each user channel conditions. LTE specifications do include several CSI feedback methods comprising periodic and aperiodic mechanisms suitable for Real Time (RT) and Non Real Time (NRT) traffic, respectively. However, such in-built schemes are quite generic and do not take into account the presence of ICIC techniques.

Bearing this context in mind, it is clear that CSI feedback must take into account the resource allocation constraints imposed by ICIC in order to optimize its operation. Both ICIC and CSI feedback have been extensively investigated, however, it is desirable a design in which CSI mechanisms are able to operate efficiently when static ICIC is also employed. As it will be shown later on, this particular interworking deserves special attention as the performance of native LTE CSI reporting schemes is poor in cases where static ICIC policies are applied. Thus, in this chapter an aperiodic CSI feedback scheme, suitable to operate in conjunction with static ICIC is presented. The proposed approach exploits two ideas:

1. Improve accuracy of CSI reports by refining the estimation of the so-called wideband Channel Quality Indicator (CQI). The CQI is a number ranging from 0 to 15 that quantifies the channel quality and refers to a recommended modulation and code rate combination; see Section 7.2.3 in (3GPP Group Radio Access Network, 2010) for details;
2. Reduce required feedback overhead by means of differential encoding.

The new aperiodic scheme, proves to be not only especially useful for bursty traffic patterns but also an excellent companion for static ICIC