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Handover decision for small cells: Algorithms, lessons learned and simulation study

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ABSTRACT

More and more cellular network operators enable the unplanned deployment of small-sized cellular stations by the end users into the predominant macrocellular network layout. This increases the spatial capacity of the cellular system and reduces the costs for installing, managing, and operating the radio access network. However, the impact of such an unplanned network densification on the robustness of cell handover (HO) still remains unclear and needs to be studied. For this purpose, in this paper we highlight the key aspects of the cell HO process in the presence of small cells and identify the main issues that affect its robustness. We summarize lessons learned from the rich literature on HO decision algorithms for small cells, and present an algorithm for alleviating interference in the cellular uplink while prolonging the battery lifetime of the user terminal. Based on the evaluation methodology of the Small Cell Forum, we conduct a comprehensive system-level simulation study to validate the accuracy of our findings and provide valuable insights on the key performance trade-offs inherent to the HO decision for small cells.

1. Introduction

Small cell deployment is currently the main answer to the seamless transfer of the exponentially increased mobile data traffic throughout the cellular network infrastructure. Compared to macrocells, small cells are characterized by low deployment and maintenance costs as well as short transmit-receive range. Femtocells are a special case of small cells that are installed and managed by the end users, reaching the core network of the cellular operator through the customers' broadband backhaul [1]. To cope with their unplanned installation, small cells offers advanced capabilities for self-optimization and healing, combined with sophisticated radio resource, interference, and security management. The support of small cells is a key feature of the Long Term Evolution-Advanced (LTE-A) system, which enables flexible network deployment, improved spectral efficiency, better user experience and cost effectiveness [2].

The denser yet unplanned deployment of small cells in LTE-A complicates all individual phases of Mobility Management (MM) when the User Equipment (UE) is in the connected mode: cell search, cell identification, and cell handover (HO). Cell search and cell identification are the inextricable preludes to the cell HO process since, in combination, they enable the UE to discover and identify small cells within proximity. On the other hand, cell HO includes all the decision and signaling processes required to seamlessly transfer the user connections from the current serving to a neighbor cell.

Even though the LTE-A Standard addresses most of the fundamental issues for MM in the presence of small cells, certain implementation-dependent issues are yet to be solved to fully utilize their potential for enhanced Quality of Service (QoS) and low-power transmission of mobile data. LTE-A supports exciting new capabilities towards improving the

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cell HO process, such as optimization of cell-specific HO parameters, employment of cell and UE signal measurements, and mobility estimation. The utilization of such features during the HO decision stage is a key enabler for avoiding frequent yet unnecessary HOs in the small cell network and alleviating the negative impact of cross-tier interference on the Signal to Interference plus Noise Ratio (SINR) performance [3]. Since the HO decision algorithm is not described in the LTE-A Standard, the employment of intelligent HO decisions in the presence of small cells can be a big competitive advantage for an operator.

In our previous work in [3], we have shed more light on the key aspects and open issues for mobility management in the presence of LTE-Advanced femtocells. Also, we have provided a comprehensive survey and classification of existing HO decision algorithms for femtocells in the LTE-Advanced system. In this paper, we exploit the classification provided in our previous work to generalize our main findings in the LTE-Advanced system of *small cells* and summarize *lessons learned* from the employment of *small cell specific* HO decisions in the LTE-Advanced system. Moreover, we present a novel HO decision algorithm for the LTE-Advanced system of small cells that alleviates network interference at the UE side (downlink direction) and prolongs the UE battery lifetime for a prescribed target SINR for the uplink. Most importantly, in this work, we provide a comprehensive quantitative performance comparison of the proposed and other existing state-of-the-art HO decision algorithms by using the widely accepted system-level simulation methodology of the Small Cell Forum [4]. To the best of our knowledge, this is the first work to quantitatively assess and compare the performance of the key design approaches for HO decision in the presence of small cells. Besides, this kind of analysis enables us to quantitatively validate the presented lessons learned from current state-of-the-art and derive useful design guidelines for HO decision tailored to the peculiar characteristics of the LTE-A small cell network.

The remainder of the paper is organized as follows. In Section 2, we describe the key aspects of the cell handover process in the presence of small cells and summarize prominent open issues that are yet to be solved for the handover decision phase in the LTE-Advanced system. In Section 3, we briefly discuss the classification provided in our previous work [3], aiming to enable the reader to better understand the lessons learned and design guidelines derived in this work. Since current literature in the area of HO decision for small cells is now relatively mature, we believe that such a discussion is crucial for the design of efficient and small cell specific algorithmic design for the LTE-Advanced small cell network. In Section 4, we introduce the proposed HO decision algorithm for the LTE-Advanced small cell network that focuses on reducing the energy expenditure and the interference experienced at the UE side. At this point, we recognize that current literature includes a noteworthy amount of HO decision algorithms focusing on reducing cross-tier interference in the uplink of the LTE-Advanced system. Nonetheless, different from existing algorithms, the proposed HO decision algorithm aims at reducing the UE energy expenditure and lowering the interference at the UE side, i.e. downlink direction of the LTE-Advanced system. In Section 5, we provide a comprehensive simulation study to validate our main findings in Section 3, to reveal the strong and weak aspects for the most prominent HO decision approaches (classes), and provide qualitative performance comparisons between the proposed algorithm and one representative algorithm from each HO decision class. In Section 6, we draw our conclusions and provide some take-away results.

2. Cell handover for small cells and open issues

Cell HO involves two main stages: HO decision and HO execution. In the presence of small cells, the short transmit-receive range brings the time horizon for cell HO closer to the one for Radio Resource Management (RRM), significantly increasing the processing and signaling overheads required for cell HO. HO decision for small cells typically involves the utilization of an enriched set of parameters on the network status [3], e.g., received signal strength (RSS), user speed, and interference. On the other hand, HO execution for small cells necessitates additional signaling to support the discovery of small cells (proximity indication), their unique identification (Physical Cell Identifier (PCI) resolution), and the employment of access control [2]. These challenges are unique to the small cell network and, if overlooked, they can increase the number of unnecessary HOs in the system, resulting in frequent service interruptions and deterioration of the QoS as perceived by the cellular users.

We consider three issues to be instrumental for HO decision in the presence of small cells: (a) optimize the HO triggering procedure, (b) employ interference-aware and energy-efficient HO decisions, and (c) attain compatibility with the cellular standard. Referring to the first challenge, existing cellular systems support a plethora of RRM capabilities at the cells, including carrier aggregation and multi-antenna transmissions. Joint optimization of the HO triggering, in conjunction with the use of advanced RRM capabilities, will enable the operators to lower the HO probability and condense the signaling overhead required for cell HO. On the other hand, the HO decision stage is a key vehicle for improving the energy-efficiency of the network nodes and handling network interference at a macroscopic level. Besides, attaining compatibility with the cellular system is not trivial, given that most of the existing HO decision algorithms utilize parameters that are not (presently) available to the access network, requiring certain functional enhancements or additional network signaling to support them.

HO execution for small cells dictates (a) smooth integration of all functions required for handing over to a small cell, and (b) careful planning/dimensioning of all auxiliary network infrastructures required to support inbound/outbound mobility to small cells, e.g., femtocell gateway (F-GW) [2]. The employment of autonomous cell search, small cell identification, and access control, should be carefully re-designed to avoid over-engineering and reduce the HO execution delay. On the other hand, even though small cells can be deployed by the users in an unplanned fashion, the installation of traffic concentrators that handle the localized traffic of small cells should be (to a certain extent) subject to network planning. For example, the strategic deployment of F-GWs based on network or geographical data can significantly reduce the control burden required for handling the femtocell traffic in the core network, e.g., in a shopping mall.