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Advanced mobility management for reduced interference and energy consumption in the two-tier LTE-Advanced network

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ABSTRACT

Femtocell deployment will play a key role for the wide adoption of LTE-Advanced, as it brings the access network closer to the end user in a cost-effective manner. This disruptive communication paradigm, however, necessitates the employment of advanced interference and mobility management to cope with the comparably denser yet unplanned network layout. This paper describes an advanced mobility management approach for the two-tier LTE-Advanced network, aiming to resourcefully utilize the femtocell superior characteristics in an energy-efficient and interference-aware manner. The key features of the proposed approach are (a) the exchange and utilization of standard signal quality measurements during the handover decision phase, to accurately estimate the mean user equipment (UE) transmit power on a per candidate cell basis, and (b) the use of a novel handover decision algorithm that jointly considers the impact of interference, power consumption, and user mobility. A comprehensive analysis of the required network signaling is provided, while extensive simulation results demonstrate that compared to existing approaches, the proposed approach attains improved performance at the cost of moderate increase of network signaling.

1. Introduction

Release 10 of the 3rd Generation Partnership Project (3GPP) for the Long Term Evolution (LTE) system, also known as LTE-Advanced (LTE-A), fulfills and even surpasses the International Mobile Telecommunications (IMT)-Advanced requirements set by the International Telecommunication Union (ITU) [1,2]. In LTE-A, a transmission to/from a mobile terminal can utilize up to five component carriers with Carrier Aggregation (CA), i.e. a deployment bandwidth of up to 100 MHz, where each component carrier uses the Release 8 structure for backwards compatibility. LTE-A supports advanced spatial multiplexing, using up to eight-layer Multiple-input multiple-output (MIMO) for the Downlink (DL) and up to four-layer MIMO for the Uplink (UL), which combined with CA leads to a peak data rate of 1 Gbps and 0.5 Gbps for the DL and UL directions, respectively. To further improve spectral efficiency, LTE-A enables enhanced single-cell DL multiuser MIMO support, while to lower the interference at User Equipments (UEs) located close to multiple evolved Node Bs (eNBs), the standard provisions for Coordinated Multipoint (CoMP) transmissions. A wide range of heterogeneous deployments are also supported by the LTE-A standard, mainly including picocells, femtocells, and relays, with the aim to extend network coverage, increase system capacity, and lower transmit power [3].

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List of acronyms

33GPP	3rd Generation Partnership Project	LTE-A	Long Term Evolution-Advanced
ANDSF	Access Network Discovery and Selection Function	MME	Mobility Management Entity
		MIMO	Multiple-input multiple-output
CA	Carrier Aggregation	QoS	Quality of Service
CSG	Closed Subscriber Group	RF	Radio-Frequency
CoMP	Coordinated Multipoint	RIP	Received Interference Power
CN	Core Network	RSS	Received Signal Strength
dB	Decibels	RSSI	Received Signal Strength Indicator
DL	Downlink	RSRP	Reference Signal Received Power
ESM	Effective SINR mapping	RSRQ	Reference Signal Received Quality
eNB	evolved Node B	RS	Reference Signals
HO	Handover	RB	Resource Block
HHM	Handover Hysteresis Margin	SINR	Signal to Interference plus Noise Ratio
HeNB	Home eNB	SC	Strongest Cell
IE	Information Element	TTT	Time To Trigger
IMT	International Mobile Telecommunications	UL	Uplink
ITU	International Telecommunication Union	UE	User Equipment

Femtocells can play a key role for wide adoption of LTE-A, as they bring the access network closer to the user in a cost-effective manner [4]. Femtocells, a.k.a., Home eNBs, are short-range, low-cost, consumer-deployed cellular access points, which interconnect standard User Equipment (UE) to the mobile operator network via the end user's broadband access backhaul. Although femtocells typically support up to a few users, they embody the functionality of a regular base station which operates in the mobile operator's licensed band. Femtocells can substantially enhance the user-perceived Quality of Service (QoS) and greatly improve the energy saving potential for the network nodes at the cost of employing more sophisticated interference and mobility management procedures.

The need for advanced interference and mobility management originates from (a) the unplanned femtocell deployment, (b) the short femtocell radius, (c) the denser network layout, and (d) the employment of access control [5]. The unplanned deployment pattern increases the Radio-Frequency (RF) interference at the LTE-A network nodes in an unpredicted manner, and complicates the mobility management procedure, e.g., the serving LTE-A cell is unable to provide a complete neighbor cell list to the UEs. On the other hand, the short femtocell radius and the denser network layout increase the number of handovers (HOs) in the system and enlarge the number of candidate cells, compromising seamless connectivity and increasing the network signaling load. Finally, access control may result in severely degraded Signal to Interference plus Noise Ratio (SINR) performance under certain interference scenarios, e.g., when an LTE-A user is not a member of a Closed Subscriber Group (CSG) femtocell in proximity [5].

Even though femtocell deployment comprises several technical challenges, it is expected to significantly reduce the energy expenditure for both the UEs and the LTE-A network. As reported in [6], if a femtocell tier is deployed, then both the mobile terminals and the cellular stations can reduce their transmit power by four to eight orders of magnitude. In-band macrocell and femtocell coexistence, however, increases the RF interference, which in turn degrades the system capacity per-tier and reduces the energy saving potential [7]. Self-optimization is another femtocell feature that leads to further energy savings. For example, the proposed dynamic pilot transmission mechanism in [8] is shown to improve the femtocell energy efficiency and reduce the occurrence of mobility events for passing outdoor users. In conclusion, even though femtocell deployment natively enhances the energy saving potential at the access network nodes, the actual energy consumption gain strongly depends on the interference and mobility management decisions employed.

This paper describes an advanced mobility management approach for the two-tier LTE-A network, aiming to lower the interference and energy consumption at the network nodes, while sustaining seamless connectivity and a prescribed mean SINR target. To achieve this, a two-step HO decision algorithm is proposed, which (a) excludes a subset of candidate cells that can compromise sustained wireless connectivity, and (b) selects the candidate cell with the minimum required mean UE transmit power for the prescribed SINR target. Both these steps are employed by adapting the HO Hysteresis Margin (HHM) according to standard LTE-A signal quality measurements, performed either by the UE or the candidate cells. The required network signaling procedure is thoroughly investigated and two different signaling approaches are identified, depending on whether an LTE-A network entity maintains and disseminates these signal quality measurements, or not. Based on the Small Cell Forum evaluation methodology in [9], it is shown that the proposed algorithm attains a significant reduction of transmit power and interference, as well as substantial improvement of system capacity and energy consumption per bit, at the cost of moderately increased network signaling load.

The remainder of this paper is organized as follows. Section 2 summarizes related works, and highlights the key aspects and contributions of this paper. Section 3