Standard-Compliant Simulation for Self-Organization Schemes in LTE Femtocells

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Abstract—**Femtocells play a critical role in LTE and LTE-Advanced networks. Their particular advantage is realized by their autonomy in management and optimization. Our interest in this work is in a special category of self-optimization use cases overseeing femtocell handovers. Specifically, we present a flexible, extendable and standards-compliant environment written in MATLAB for studying handover related self-optimization schemes. The paper describes the overall structure and design of the environment, and offers a detailed explanation of the different modules involved. Sample results that validate the environment are also given. To the best of our knowledge, no such environment has been publicly accessible so far.**

Index Terms—**Femtocells; Self optimization; handovers; LTE; LTE-Advanced; simulation.**

I. INTRODUCTION

Long Term Evolution (LTE) femtocells are projected to reach as high as 28 million units by 2017 [1]. To facilitate this wide deployment, automatic control-parameter adjustments should be made by implementing Self Organizing Network (SON) capabilities. Our focus in this work is on handover related self optimization use cases taking place in the handover preparation phase of the LTE handover procedure. The objective is to build a simulation environment that provides a unified LTE femtocell simulation environment according to the recommendations and standards. Ultimately, this simulation environment enables fair and valid comparisons while still being extendable to LTE-Advanced and many self organization use cases.

Examples of commercial LTE simulators include [2] and [3]. Few researchers have made their LTE simulators source code available publicly [4]. None has built a public LTE or LTE-Advanced femtocell simulation environment which enables SON use case implementations. In fact, if we require these environments to be available in MATLAB, then no such option is publicly accessible as far as we know. The next section briefly describes the overall LTE handover procedure. Section III introduces the simulation environment. Sample results are then offered in Section IV. Finally, Section V concludes and outlines future work.

II. BACKGROUND

According to [5], the LTE handover procedure starts in the **RRC IDLE state** by having the UE scanning neighbouring cells Reference Signal Received Power (RSRP) levels. The cell with the highest signal strength is chosen to "camp on". By the time the user initiates a call, an attempt is made to transition to the **RRC CONNECTED state**. The UE starts by selecting the neighbouring target cell with the highest signal strength. If this user's new call request was blocked, then a barring timer would be triggered [6] in which the UE returns back to the RRC IDLE state and engages in the same cell selection procedure described above. Choosing the same target cell by the same UE is barred until this timer expires or reset if the user has managed to access another target cell. By the time the transition is made, the UE will start sending neighbourhood measurements to the source cell. The source cell decides to send a handover request to the target cell that has the highest signal strength level if the following condition is met [7] for a duration of TReselection:

$$Q_{meas,n} > Q_{meas,s} + Qoffset_{s,n} + QHyst_s{}^1$$

where:

$Q_{meas,n}$	is the RSRP measurement of the neighbouring cell in dBm.
$Q_{meas,s}$	is the RSRP measurement of the serving cell in dBm.
$Qoffset_{s,n}$	is the cell individual offset of the neighbouring cell as stored in the serving cell in dB.
$QHyst_s$	is the handover hysteresis margin of the serving cell in dB.

In all cases, handover requests are initiated only if the user has spent at least 1 second at the current serving cell. If the target cell rejects a handover request, then we will have a **Handover Failure** which if repeated could lead to a **Radio Link Failure**. However, if the handover request is granted, then the handover execution phase followed by the handover completion phase is initiated. If the user spends less than 5 seconds in the target cell(s) before returning back to the same source cell, then the handover is considered a **Ping Pong Handover**.

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[1] The same abbreviations are used by the 3GPP UE connected mode procedures specification [8].

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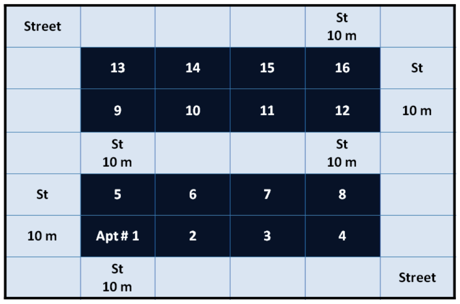

Fig. 1. An illustration of network topology.

TABLE I
PARAMETERS USED IN SIMULATION SCENARIO.

Item	Assumption
Center Carrier Frequency	2 GHz
Downlink System Bandwidth	3 MHz
Macrocell Intersite Distance	1732 metres
Macrocell Antenna	3-Sector antennas
Femtocell Antenna	Omnidirectional
Macrocell DL TX Power Level	Fixed: 43 dBm
Femtocell DL TX Power Level	Varied: 2-20 dBm
Initial barring Timer value	15 seconds
UE Class	1
UE Class's Peak Data Rate	10 Mbps
Minimum acceptable SINR level	-10 dB
UE Receiver Sensitivity	-110 dBm

III. SIMULATION ENVIRONMENT

A. *Scenario*

As recommended by the Small Cell Forum in [9], we assume that the simulation scenario has the network topology shown in Figure 1 with a randomly dropped femtocell at each apartment. This apartment block is located at the intersection area of three macrocell sectors where the macrocellular tier coverage is expected to be limited and therefore no macrocell would be chosen by the UEs. This scenario is made to have an overall network performance that captures the effect of the self optimization schemes being implemented only in the femtocellular tier. Surrounding these three macrocell sectors are two rings of macrocells to account for the macrocell tier interference.

The femtocell's downlink transmission power level is set depending on interference conditions. Users can either be indoor or outdoor in vehicles. The same standardized cell barring technique is assumed for handover failures in order to avoid unnecessary ones. The same NGMN recommended traffic mix is adopted as indicated in [10], which is 30% VoIP, 20% Interactive Gaming, 20% Near Real Time Video Streaming, 20% HTTP and 10% FTP. Table I summarizes the simulation scenario assumptions.

B. *Structure*

The simulator is written in approximately 8000 lines of MATLAB [11] code with the structure shown in Figure 2. It is composed of nine modules where the unidirectional arrows represent the fact that a module just receives/sends from/to others, while the bidirectional arrows represent the mutual exchange of information. In what follows, we go through each module while further elaboration can be found in our thesis work in [12].

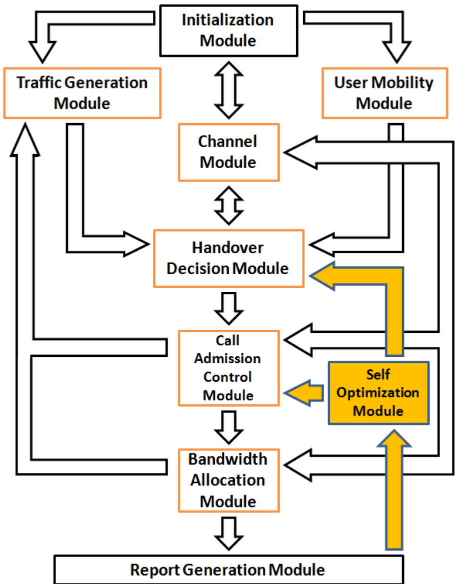

Fig. 2. Simulator overall structure.

1) Initialization Module: This module initializes both the User Mobility Module and the Traffic Generation Module. It also initializes the user states and the access point states by running the femtocell downlink transmission power control scheme based on the measurement based method followed in [13] and interacting with the Channel Module. The objective is to achieve a zero-dB-SINR value at the femtocell boundary set initially to the femtocell's apartment edge.

2) Channel Module: This module provides other modules with RSRP, SINR and throughput estimations. It starts with the shadow fading maps which are generated according to the correlation matrix based method followed in [14]. These maps are used to compute the auto-correlated shadow fading values. These fading values, the path loss models and the thermal noise are all used to compute the RSRP levels of both the serving cell and the interfering cells and compute SINR afterwards. Similar to [15], no fast fading is simulated. Moreover, and similar to the assumptions made in [16], a flat power spectral density is assumed. It is also assumed that the intra-cell interference is eliminated with OFDMA, and that the inter-cell interference depends on the interfering cell loads which can be used as an indication for the probability of causing interference. This simplified method of computing the interference is adopted by several authors including [17], [18], [19]. Further details about the SINR computation assumptions, as recommended by the Small Cell Forum in [9], can be found in our thesis work in [12].

The throughput is estimated using the attenuated and truncated Shannon's Capacity formula as explained by the Small

Cell Forum in [9]. When using this formula, the attenuation is considered to account for the inherent implementation losses, including the Cyclic Prefix Loss and the Reference Symbol Loss as explained in [20].

3) User Mobility Module: This module generates users mobility events. It starts from the users locations given by the Initialization Module and then updates other modules with the new user locations. Indoor users are assumed to walk randomly inside each apartment while outdoor users are mobilizing in the streets periodically in a predetermined path with a fixed velocity.

4) Traffic Generation Module:

VoIP: both voice active and inactive periods are modelled with an exponential time distribution of a 1.25 second mean. A 16 kbps constant throughput is assumed in the active period and a complete silence in the inactive period. This throughput is assumed to be the minimum to avoid a call drop or block.

Interactive Gaming: the first downlink packet starts within the first 40 msec. After that, a fixed 57 kbps throughput is assumed. This assumption is made after considering 1 million samples of packet sizes and packet arrival times according to the distributions given in [14]. This throughput is assumed to be the minimum for a gaming session to be maintained.

Near Real-Time Video Streaming: at the beginning, the user's video playout buffer is full with 320 k of video streaming bits. In order to prevent user outage due to the 64 kbps video streaming service, the base station streaming video bits needs to be transmitted in a near real-time fashion.

HTTP: the main object size and its parsing time are modelled according to [14]. This also applies to the embedded objects sizes, their number and the time needed to read the webpage afterwards. A throughput of 128 kbps is assumed to be the minimum required throughput to maintain the service.

FTP: similar to HTTP traffic, the FTP traffic in terms of the file size and reading time follows the evaluation methodology given in [14]. A throughput of 128 kbps is assumed to be the minimum required throughput to maintain the service.

5) Handover Decision Module: This module receives users current locations and traffic status from the User Mobility Module and the Traffic Generation Module, respectively. It executes the UE's neighbourhood discovery scanning by interacting with the Channel Module. A user's call is dropped or blocked if there is no cell with a signal level that is higher than the UE receiver sensitivity. If so, the Traffic Generation Module is informed of such an event to generate a new call request. After a successful neighbourhood discovery, the Handover Decision Module can make its handover decision according to the LTE standard or any other mechanism. This decision is sent afterwards to the Call Admission Control Module.

6) Call Admission Control Module: This module can give a higher priority for handover calls over new calls with its conventional guard channel policy threshold. The requesting service bandwidth estimate is made by referring back to the Channel Module. If the request was granted, then the handover request or the new call request goes through a presumed fixed signalling delay. However, if the request was rejected then we would have either a handover failure or just a call block, where both cases initiate a barring timer. In case of a call block, the Traffic Generation Module is informed of such an event.

7) Bandwidth Allocation Module: This module grants handover and new call requests final resources. It monitors the call statuses and decide whether some calls will need to be dropped if they fail to meet their minimum throughput or minimum SINR level requirements. During this process, this module needs to interact with the Channel Module. It also needs to report call drops to the Traffic Generation Module.

8) Self Optimization Module: This module is where all of the femtocell handover related self optimization schemes are implemented. It is fed by the Report Generation Module with the Key Performance Indicators (KPIs) needed to adjust the fixed control parameters of both the Handover Decision Module (e.g. $QHyst$, TReselection and $Qoffset$) and the Call Admission Control Module (e.g. guard channel policy threshold).

9) Report Generation Module: This module provides a graphical user interface that allows us to visualize network topology, users movement, femtocell coverage areas and instantaneous loads. This module also allows validation tests by producing an AVI video file for the entire simulation, user traces and cell traces.

IV. SAMPLE RESULTS

In Figure 3 and Figure 4, we show the Handover Failure Ratio (HOFR) and the Ping Pong Handover Ratio (PPHOR), respectively. Four different cases are considered: the Static case where no self optimization scheme is implemented, the HandOver Self Optimization (HO-SO) case where the Simplified Trend-based scheme proposed by [21] is implemented, the Call Admission Control Self Optimization (CAC-SO) case where the scheme proposed by [22] is implemented and the Load Balancing Self Optimization (LB-SO) case where the scheme proposed by [23] is implemented. These representative schemes and KPIs are chosen solely for demonstration purposes.

In this particular evaluation, the HO-SO scheme has managed to decrease both HOFR and PPHOR by restricting the number of outbound handovers including handover failures and ping pong handovers. The CAC-SO scheme gives handovers a higher priority over new calls which results in decreasing HOFR. However, the CAC-SO scheme does not differentiate between ping pong and normal handovers which leads to no clear effect on PPHOR. Finally, the LB-SO scheme always tries to balance the network load which results in a higher chance of acceptance for handovers (lower HOFR) at the expense of increasing PPHOR.

V. CONCLUSION AND FUTURE WORK

Self organization is fundamental to femtocell autonomy, and has thus motivated the development of many self organization use cases. Our aim in this work was to introduce a realistic, standard-compliant simulator for LTE femtocells with a special emphasis on evaluating handover related self optimization

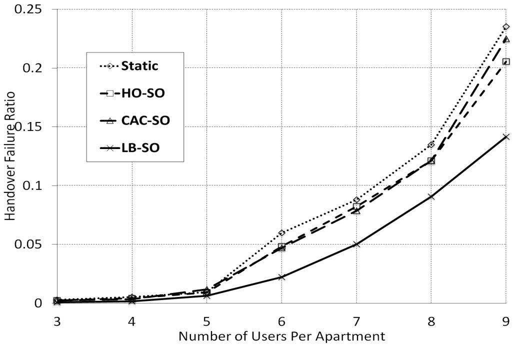

Fig. 3. Handover Failure Ratio vs. number of users under different handover-related self-optimization schemes.

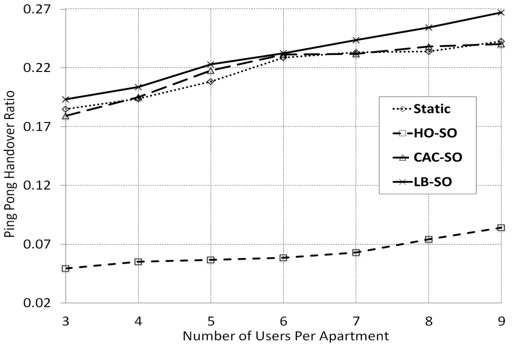

Fig. 4. Ping Pong Handover Ratio vs. number of users under different handover-related self-optimization schemes.

schemes. The environment, however, is extendible to other self organization schemes, as well as to accomodating specifications of LTE-Advanced networks. For our future work, we will be studying the effect of implementing handover related self optimization use cases simultaneously. We would also enhance our simulation environment by adding other self organization use case modules. Finally, plans are underway to make the enhanced LTE femtocell simulation environment accessible online for the research community at large.

VI. ACKNOWLEDGMENT

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