Understanding the Interactions of Handover-Related Self-Organization Schemes

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ABSTRACT

A Self Organizing Network (SON) scheme monitors certain Key Performance Indicators (KPIs) and responds by adjusting system control parameters. Multiple SON schemes may have related KPIs or use the same control parameters. This leads these schemes and their use cases to interact either constructively or destructively. In this paper, we study these interactions between three SON use cases all aiming at improving the overall handover procedure in LTE femtocell networks. These use cases are namely: handover self optimization, call admission control self optimization and load balancing self optimization. This work is motivated by the lack of interaction studies conducted so far between these three self optimization use cases. First, we have surveyed related individual scheme proposals in order to identify schemes which represent these three use cases in our interaction study. Then, several interaction experiments are conducted in realistic scenarios using our in-house built and LTE-compliant simulation environment. We conclude by drawing guidelines that we believe can help designers realize better coordination policies between these three handover-related SON use cases.

Categories and Subject Descriptors

C.2.1 [**Computer-communication Networks**]: Network Architecture and Design–*wireless communication, distributed networks*; C.4 [**Performance of Systems**]: *performance attributes.*

Keywords

Femtocell; LTE; Self Organizing Network; Optimization; Handover; Call Admission Control; Load Balancing; Interaction; Coordination; Simulation.

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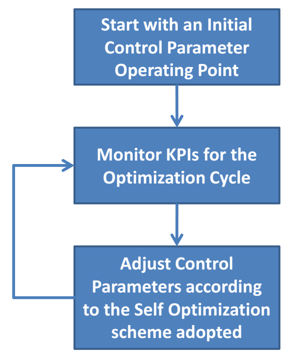


Figure 1: **Self Optimization Scheme Cycle**

1. INTRODUCTION

It is expected that 28 million femtocell units are to be deployed by 2017 [1]. Such high scale ad hoc deployments will face the major challenge of frequent system control parameter adjustments. This challenge is addressed by adopting SON use cases. Self optimization use cases, a subclass of SON use cases, are all based on implementing a scheme that monitors KPIs and adjusting system control parameters in response. An initial operating point is defined by the initial control parameter values. These control parameters can be either standardized or scheme-specific. Figure 1 illustrates this self optimization scheme cycle.

However, interactions could occur when several SON use cases, with related KPIs and/or common control parameters, are simultaneously operating in the same network. These interactions could either be positive or negative. In this work, we address three interacting SON use cases all aiming at enhancing the overall handover process in LTE femtocell networks. They are namely: handover self optimization, call admission control self optimization and load balancing self optimization.

This paper is organized as follows: in Section 2, we briefly review the overall LTE handover procedure. The definitions of the three handover-related self optimization use cases in light of some of the most commonly used KPIs are also defined in this section. This background section helps in identifying possible interaction scenarios between the handover-related self optimization use cases of interest. In Section 3, we first survey previous interaction studies to show the need for an interaction study that gathers the chosen handover-related self optimization use cases. After that, proposed individual schemes are surveyed and representative schemes are chosen. Section 4 first presents the individual scheme experiments and then the mutual scheme interaction experiments. Individual experiments are conducted first to verify that each representative scheme meets its use case objective. In order to have realistic scenarios and due to the lack of such environments, all of these experiments are conducted in our in-house LTE compliant simulation environment [2]. Section 5 discusses experiment results and gives some guidelines which we believe should be followed when coordinating the handover-related self optimization use cases covered in this work. Finally, Section 6 concludes our findings and outlines future work.

2. BACKGROUND

2.1 Handover Procedure

There are three main phases in the overall LTE handover procedure: preparation, execution and completion. The handover preparation phase is when handover decisions are made at the source cell and admission decisions are made at the target cell. Therefore, it is the phase at which the three handover-related SON use cases take place.

In the Radio Resource Control (RRC) IDLE state, the UE always seeks to identify a suitable cell with the highest signal strength to "camp on". In fact, RRC IDLE state handovers are UE controlled. When transitioning from the RRC IDLE state to the RRC CONNECTED state, the UE begins by selecting the neighbouring target cell with the highest signal strength. If this cell selection request is rejected, then a barring timer will be triggered and the UE returns back to the RRC IDLE state [3]. Until this timer is expired, choosing the same target cell by the same UE is barred. However, if the UE manages to access another target cell, the timer will reset and an RRC connection will be established (RRC CONNECTED state). In this state, the UE starts the handover procedure by sending measurements to the current source cell which is responsible of making any future handover decisions. Therefore, RRC CONNECTED state handovers are network controlled but still UE assisted.

During the RRC CONNECTED state, the cell with the highest signal strength is chosen for handover if the following condition is met for a duration of at least TReselection and after at least 1 second of dwelling time at the current source cell [4]:

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

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.

Both $QHyst$ and TReselection are system control parameters which can affect handovers globally. Whereas, $Qoffset$ is a cell-pair specific system control parameter which can affect handovers only between the corresponding serving-neighbouring (source-target) pair of cells.

If the target cell denies the source cell handover request, then we will have a **Handover Failure**. Successive handover failures could eventually lead to a **Radio Link Failure**. However, if the handover request is granted, the handover execution phase is initiated followed by the handover completion phase. If the user spends less than 5 seconds in the target cell(s) before returning back to the same source cell, the handover is considered a **Ping Pong Handover**.

2.2 Handover-related Self Optimization

This process starts with the adjustment of the femtocell's coverage footprint by self optimizing its handover-related control parameters (e.g. QHyst, TReselection,Qoffset or the conventional admission control guard channel policy threshold). Before introducing the three handover-related self optimization use cases, we define some of the most commonly used KPIs as follows:

- Handover Failure Ratio (**HOFR**): the ratio between the the Number of Handover Failures and the total summation of the Number of Handover Failures and the Number of Successful Handovers.
- Ping Pong Handover Ratio (**PPHOR**): the ratio between the Number of Ping Pong Handovers and the total summation of the Number of Handover Failures and the Number of Successful Handovers.
- Call Dropping Probability (**CDP**): the ratio between the Number of Radio Link Failures and the Number of Accepted Calls into the cell.
- Call Blocking Probability (**CBP**): the ratio between the Number of Call Blocks and the total summation of the Number of Call Blocks and the Number of New Calls.

The three handover-related self optimization use cases can now be introduced as follows:

- **Handover Self Optimization:** the effect of this use case takes place at the source cell. The main task is to reduce HOFR and PPHOR.
- **Call Admission Control Self Optimization:** the effect of this use case takes place at the target cell. The main task is to admit as many calls as possible while maintaining an acceptable level of service for the ongoing calls. This usually leads to decreasing HOFR and CDP.
- **Load Balancing Self Optimization:** the effect of this use case takes place at the source cell. The main task is to balance the load across the network cells in order to decrease both HOFR and CBP. This comes at the cost of increasing PPHOR.

As it can be seen, these use cases might monitor some related KPIs which might lead to interactions. **Negative interactions** occur when one of the interacting schemes contradicts or limits the benefits of the others, whereas **Positive interactions** occur when the interacting schemes help each other improve the overall network performance. This judgment should be made in light of the different KPIs while considering that interactions might be negative for one use case but positive for the other.

3. RELATED WORK

3.1 Interaction Studies

The authors in [5] study the interaction between a handover self optimization scheme and a load balancing self optimization scheme. The handover self optimization scheme is based on adjusting QHyst and TReselection while being triggered by a high HOFR, a high CDP or a high PPHOR. The load balancing self optimization scheme is based on adjusting Qoffset while being triggered by the load differences between neighbouring cells. In both [6] and [7], the work done in [5] is enhanced by prohibiting the handover self optimization scheme from causing backward handovers.

The authors in [8] study the interaction between a handover self optimization scheme and a call admission control self optimization scheme. The handover self optimization scheme is based on periodically monitoring the trend followed by a weighted summation of HOFR, CDP and PPHOR. Depending on this trend, new QHyst and TReselection values are chosen. For the call admission control self optimization scheme, the conventional guard channel policy is adopted with a dynamic threshold. The monitored KPIs are HOFR, the ratio of calls with a low throughput and CBP. Both schemes are interacting constructively in terms of achieving a lower HOFR and a lower CDP, while no effect is taking place between them in terms of PPHOR. The call admission control self optimization scheme is benefiting from this interaction by blocking less calls.

To the best of our knowledge, no further interaction studies have been conducted to date between the SON use cases of interest here. This has led us to conduct the following survey in order to identify the representative schemes to be used in this study.

3.2 Handover Self Optimization (HO-SO)

3.2.1 *Overview of Schemes*

In reference [9], the authors propose an empirical formula that uses the current cell load and type in order to modify the UE RSRP measurement received and therefore affect future handover decisions. Other schemes adjust standardized control parameters. In reference [10], either QHyst or TReselection is adjusted in reaction to three handover defect types which are: Too Early Handovers, Too Late Handovers and Handovers To Wrong Cells. The scheme differentiates between these three handover defect types by measuring their HOFR, PPHOR and CDP. Based on this, a decision is made on how different control parameter adjustments should be made.

Contrary to [10], the authors in [11] claim that adjusting Qoffset gives more flexibility. They also exploit the fact that different handover defect types dominate depending on the user mobility status and therefore different Qoffset adjustments should be made.

A multi-control parameter adjusting scheme is proposed in [12]. The scheme starts by exchanging with neighbouring cells the number of radio link failure events, the number of too early handover events and the number of handover to wrong cell events. If their weighted summation exceeds a threshold value, then the scheme starts checking whether a global optimization or a local optimization is necessary. QHyst and TReselection are adjusted in global optimization attempts and the relevant Qoffsets are adjusted in local optimization attempts.

Three multi-control parameter adjusting schemes are proposed in the European Union (EU) project of Self Optimization and self ConfiguRATion in wirelEss networkS (SOCRATES) [5]. These schemes are: the Simplified Trend-based scheme, the Trend-based scheme and the Handover Performance Indicator Sum-based scheme. The Simplified Trend-based scheme periodically monitors HOFR, CDP and PPHOR. The trend followed by each KPI is determined by comparing its current value against its predefined threshold. Based on the trend detected, both the standardized QHyst and TReselection control parameters are adjusted.

The Trend-based scheme still monitors the same KPIs adopted by the Simplified Trend-based scheme but does not run periodically. In fact, it starts by verifying that the network is experiencing a tangible and lasting trend and then changes the handover operating point, as defined by QHyst and TReselection, according to an empirical criteria [13].

The Handover Performance Indicator Sum-based scheme works periodically like the Simplified Trend-based scheme. It monitors a weighted summation of HOFR, CDP and PPHOR and then compares this summation value to its most recent value. If a performance improvement is detected, then the same optimization direction is followed, otherwise the optimization direction is reversed. The same empirical criteria mentioned in [13] is adopted. However, the drawback here is that any slight handover performance indicator change may cause a change in the optimization direction needlessly. Therefore, authors in [14] propose a strategy that would prevent the optimization direction from switching back unless the handover performance indicator change percentage is higher than a threshold called the "Performance Degradation Percentage" (PDP). A very high PDP can result in tolerating an excessive handover degradation before reacting and changing the optimization direction. As a result, a T-test is proposed by authors in [15] to be implemented just before the PDP strategy which yields the Enhanced Handover Performance Indicator Sum-based scheme.

3.2.2 *Representative Scheme*

We choose the Simplified Trend-based scheme proposed by [5] as the handover self optimization representative scheme. Algorithm 1 shows the pseudocode. This scheme is chosen for the following reasons:

- It is a multi-control parameter adjusting scheme, which gives more flexibility in altering handover decisions,
- Both QHyst and TReselection are commonly used standardized control parameters,
- It is generic and does not rely on any empirical formula,
- Lastly, it is based on monitoring locally processed KPI measurements with no signalling needed.

This scheme starts by initializing the operator KPI thresholds. Then, it periodically measures the local HOFR, CDP and PPHOR in order to evaluate how QHyst and TReselection should be changed. Most importantly, this scheme trades off HOFR and PPHOR with CDP.

Algorithm 1 HO-SO Representative Scheme

```
Initialize HOFR_TH, CDP_TH and PPHOR_TH
while Cell is ON do
  if an optimization interval has passed then
    Compute optimization interval HOFR, CDP and PPHOR
    if HOFR<HOFR_TH and PPHOR<PPHOR_TH then
      if CDP>CDP_TH then
        Decrease QHyst;
        Decrease TReselection;
      else
        Decrease HOFR_TH;
        Decrease CDP_TH;
        Decrease PPHOR_TH;
      end if
    else
      if CDP≤CDP_TH then
        Increase QHyst;
        Increase TReselection;
      else
        Increase HOFR_TH;
        Increase CDP_TH;
        Increase PPHOR_TH;
      end if
    end if
  end if
end while
```

3.3 Call Admission Control Self Optimization (CAC-SO)

3.3.1 *Overview of Schemes*

All of the schemes surveyed in this category are based on bandwidth reservations. To begin with, the authors in [16] claim that reserving resources for real-time calls would not automatically prevent these delay intolerant services from being dropped, whereas reserving resources for non-real-time calls would at least result in reducing congestions. Therefore, a scheme that reserves resources for non-real-time calls is proposed. The reservation threshold is adjusted periodically based on the packet drop rate.

The authors in [17] and [18] propose schemes which prioritize handover calls over new calls by adopting the conventional guard channel policy with a dynamic threshold. In reference [17], the dynamic threshold is adjusted in response to HOFR and the number of successful handover attempts; authors claim that reacting to low HOFR after a number of successful handover attempts prevents the system from oscillating. In reference [18], the scheme monitors HOFR, CDP and the fraction of calls with a throughput lower than the minimum throughput required by the packet scheduler. This scheme tends to increase the dynamic guard channel threshold faster than decreasing it which gives handovers a higher priority over new calls.

The authors in [19] derive users handover probabilities based on their predictable mobility habits. Admission decisions are based on these probabilities and a dynamic threshold. Handovers are prioritized over new calls by not subjecting them to this threshold. The monitored KPI is HOFR.

The work in reference [20] is the only scheme that prioritizes handovers over new calls while still differentiating between real-time and non-real-time calls. Real-time new calls are admitted only if the desired amount of bandwidth is available at the target cell and its neighbours, whereas real-time handovers are given a higher priority by being satisfied even with the minimum bandwidth at the target cell and its neighbours. However, non-real-time handovers and new calls consider only the target cell when making such admission decisions. This gives them a higher priority over real-time calls. In all cases, a reserved bandwidth pool is increased if HOFR is higher than a predetermined threshold value and vice versa.

3.3.2 *Representative Scheme*

We choose the scheme proposed by [17] as our call admission control self optimization representative scheme. Algorithm 2 shows the pseudocode. However, we have modified the scheme slightly in order to account for the mobile operator's call blocking probability threshold, and to make the mobile operator thresholds adjustable if they were initially set to extremely low or high values. These modifications are shown on lines 6 through 10 and 15 through 22. This scheme is chosen for two reasons:

- It is based on the most commonly used dynamic guard channel policy which prioritizes handover calls over new calls,
- It monitors the locally processed HOFR and therefore no signalling is needed.

This scheme starts by initializing the operator KPI thresholds. Then, it periodically measures the local HOFR and CBP in order to evaluate how the guard channel policy's dynamic threshold (CAC_TH) should be adjusted. The two parameters (α_1 and α_2) are used to prevent oscillations, where $\alpha_1 > \alpha_2$ and both $\alpha_1 \& \alpha_2 < 1$. Responses to high HOFR are accelerated by including the Number of Handover Failures (NHOF), whereas responses to low HOFR are slowed down by including the Number of Successful Handovers (NSHO). This gives handovers a higher priority over new calls. Most importantly, this scheme trades off HOFR with CBP.

3.4 Load Balancing Self Optimization (LB-SO)

3.4.1 *Overview of Schemes*

All of the schemes surveyed in this category are based on adjusting the cell coverage area either actually, by adjusting the transmission power or virtually, by adjusting Qoffset. An exchange of cell load information is always needed.

In reference [21], a scheme is proposed that is based on adjusting the transmission power in response to the current cell load. It starts by exchanging neighbouring cells load information and then compares current cell load with the neighbouring cells average load. If this average load is lower than the current cell load, then the current cell power is decreased and vice versa. The scheme also controls the current cell's minimum power level in order to avoid gaps and overlaps. Gaps are detected whenever a high CDP is encountered whereas the opposite applies for overlaps.

The authors in [22] claim that trying to balance the load using power adjustments can still result in gaps and overlaps.

Algorithm 2 CAC-SO Representative Scheme

```
Initialize HOFR_TH and CBP_TH
while Cell is ON do
  if an optimization interval has passed then
    Compute optimization interval HOFR and CBP
    if HOFR≥α1×HOFR_TH and NHOF>0 then
        if CBP≤CBP_TH then
            Decrease CAC_TH;
        else
            CAC_TH=CAC_TH;
        end if
    end if
    if HOFR≤α2×HOFR_TH and NSHO≥NSHO_TH then
        Increase CAC_TH;
    end if
    if HOFR<HOFR_TH and CBP<CBP_TH then
        Decrease HOFR_TH;
        Decrease CBP_TH;
    end if
    if HOFR>HOFR_TH and CBP>CBP_TH then
        Increase HOFR_TH;
        Increase CBP_TH;
    end if
  end if
end while
```

Therefore, a scheme that is based on monitoring cell loads and adjusting Qoffsets is proposed.

Several other schemes are based on adjusting Qoffsets. In reference [23], the authors propose that Qoffsets should be adjusted in response to the CBP difference between cells. This difference along with the current Qoffset values are used as inputs to a fuzzy logic algorithm in order to make Qoffset adjustments. The authors in [24] propose a Qoffset-adjusting scheme based on an Autonomic Flowing Water Balancing Method (AFWBM) inspired by the connected vessels theory in physics.

The work in [25] is the only scheme that is based on adjusting both the transmission power and Qoffsets. Similar to [23], both of these adjustments are made using a fuzzy logic controller. For the Qoffset adjustments, the fuzzy inputs are the current Qoffset values and the difference in the load ratios between the two cells targeted by the load balancing, whereas the outputs will be the adjusted Qoffsets. For the power adjustments, the fuzzy inputs are the difference in the load ratios, the difference between the current cell transmission power level and its default level, and another input called the ping pong parameter. With a low ping pong parameter, the power adjustment process would be stopped to avoid causing gaps and overlaps. The outputs of this power adjustment process are the required transmission power levels.

3.4.2 *Representative Scheme*

We choose the scheme proposed by [22] as our load balancing self optimization representative scheme. Algorithm 3 shows the pseudocode. This scheme is chosen for the following two reasons:

- It avoids causing coverage gaps and overlaps by not adjusting the cell transmission power levels,
- It adjusts the commonly used standardized Qoffset control parameters.

Algorithm 3 LB-SO Representative Scheme

```
Initialize Load_Diff_TH
while Cell is ON do
  if an optimization interval has passed then
    for all neighbouring cells do
        Collect last optimization interval CL_n
    end for
    for all neighbouring cells do
        if CL_n − CL_s >Load_Diff_TH then
            Increase Qoffset_{s,n};
        end if
        if CL_n − CL_s <Load_Diff_TH then
            Decrease Qoffset_{s,n};
        end if
        if abs(CL_n − CL_s) ≤Load_Diff_TH then
            Qoffset_{s,n} = Qoffset_{s,n};
        end if
    end for
  end if
end while
```

This scheme starts by initializing the operator load difference threshold (Load_Diff_TH). Then, it periodically measures the serving cell load (CL_s) and the neighbouring cell loads (CL_n) in order to evaluate whether Qoffset should be decreased, increased or stay the same. All of these adjustments are processed locally after gathering load information from the neighbouring cells. Most importantly, this scheme trades off PPHOR with CBP and HOFR.

4. EXPERIMENTS

4.1 Scenario

The network topology is shown in Figure 2. Each apartment has one randomly dropped femtocell. This apartment block is located at the intersection area of three macrocell sectors where the macrocellular tier coverage is expected to be limited. Surrounding these three macrocell sectors are two rings of 3-sector macrocells to account for the macrocell tier interference affect. The resulting weak macrocell coverage, reaching our topology area, leads the user handsets to never choose the macrocellular tier for their new call and handover requests. In fact, we have found that adopting this scenario has successfully led the network performance to capture exclusively the effect of the self optimization schemes being studied and implemented only in the femtocellular tier. Reader should refer to our thesis work in [2] for experiments confirming these findings.

We adopt the measurement based method [26] to set the femtocells downlink transmission power levels. However, thermal noise, shadow fading, all interfering macrocell and femtocell signals are all considered. Indoor users walk randomly while bouncing back at each apartment walls. Five vehicles, with one user in each vehicle, are mobilizing in the streets periodically in a predetermined path with a fixed velocity. The same standardized cell barring technique, as discussed in Subsection 2.1, is assumed for handovers.

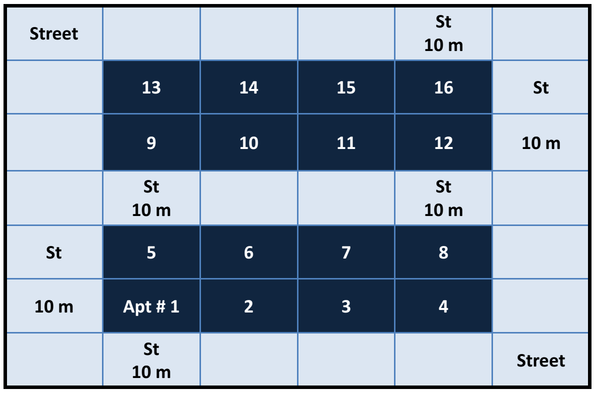


Figure 2: **An illustration of network topology**

The traffic mix of 30% VoIP, 20% Interactive Gaming, 20% Near Real Time Video Streaming, 20% HTTP and 10% FTP is adopted. For VoIP, Interactive Gaming and Near Real-Time Video Streaming services, the active and the idle call durations are drawn from exponential distributions. Whereas, both HTTP and FTP services are assumed to continuously download webpages and files each time reading finishes. The reading times are drawn also from exponential distributions. Table 1 summarize the most important simulation scenario assumptions. Our thesis work in [2] gives further details about the simulation environment including SINR computations and the representative scheme assumptions made.

Table 1: **Parameters used in simulation scenario**

Item	Assumption
Center Carrier Frequency	2 GHz
Downlink System Bandwidth	3 MHz
Number of PRBs	15
Number of Macrocells	36
Macrocell Intersite Distance	1732 metres
Number of femtocells	16
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
Outdoor User Vehicle Speed	30 km/h
Initial barring Timer value	15 seconds
UE Number of Receiver Antennas	1 (SISO)
UE Class's Peak Data Rate	10 Mbps
Minimum acceptable SINR level	-10 dB
UE Receiver Sensitivity	-110 dBm

The following set of abbreviations are adopted in all of our upcoming mutual interaction experiment figures:

- **Static:** represents the Static control parameters or simply the fact that no self optimization scheme is implemented.
- **HOCAC-SO:** represents the interaction between the representative HO-SO scheme and the representative CAC-SO scheme.
- **HOLB-SO:** represents the interaction between the representative HO-SO scheme and the representative LB-SO scheme.
- **CACLB-SO:** represents the interaction between the representative CAC-SO scheme and the representative LB-SO scheme.

For the three handover-related self optimization schemes when operating simultaneously, we notice that no additional three-scheme interactions are observed. Reader should refer to our thesis work in [2] for further details.

4.2 Individual Experiments

Figure 3 shows the representative schemes performance in terms of HOFR, CDP, CBP and PPHOR. We notice that in femtocell environments, PPHOR is high which leads the HO-SO scheme to aggressively increase its QHyst and TReselection parameters while decreasing the number of outbound handovers, PPHOR and HOFR. However, this leads these outbound handovers to be locked to a femtocell that has a signal strength that is lower than its neighbours which will eventually lead to call drops, an increased CDP, a less utilization and therefore a less CBP.

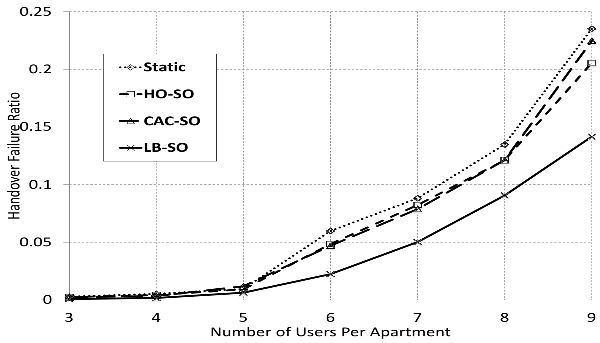
We also notice that CAC-SO scheme prioritizes handovers over new calls which leads to more new call blocks, less handover failures and therefore less call drops. Less call drops are due to the fact that users are getting their handover requests granted. However, this scheme does not clearly differentiate between normal and ping pong handovers, which means no clear effect on PPHOR.

Finally, LB-SO scheme always tries to balance the load as soon as it discovers a tangible load difference. This balancing enhances the chances for new calls and handovers of finding bandwidth which decreases both HOFR and CBP while increasing PPHOR. However, and since the main cell selection/reselection criterion is based on choosing the cell with the highest signal strength, most of the overutilized cells would be the cells with the highest downlink transmission power levels and vice versa. Therefore, this load balancing technique forces users to leave the higher power overutilized cells to the lower power underutilized cells which means a higher interference for these users and as a result an increased CDP.

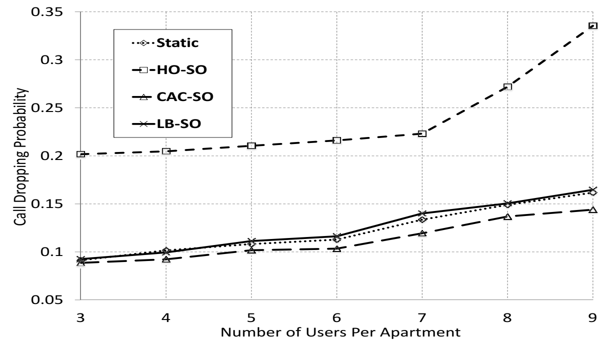
4.3 Interaction Experiments

4.3.1 *HOCAC-SO schemes interaction*

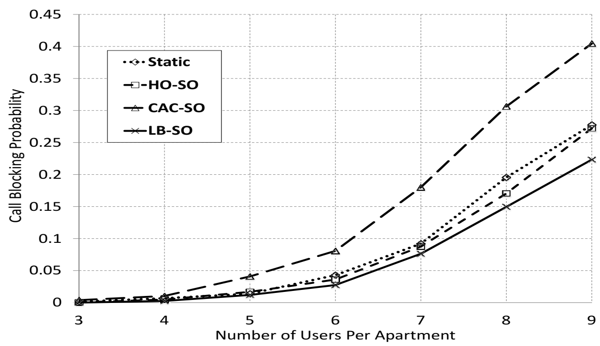
Figure 4 shows this performance interaction in terms of HOFR, CDP, CBP and PPHOR. We find that the CAC-SO scheme at the target femtocell guards some resources to the handover requests initiated by the HO-SO scheme at the source femtocell. This makes the CAC-SO scheme share the burden of decreasing HOFR with the HO-SO scheme and overall we have an even less HOFR. The HO-SO scheme is now using a bit smaller QHyst and TReselection parameters and therefore we have a slight CDP decrease but a slight PPHOR increase. In addition, the CAC-SO scheme now neither needs to reserve as many resources for handovers nor block as many new calls. Therefore, the system experiences a slight CBP decrease.



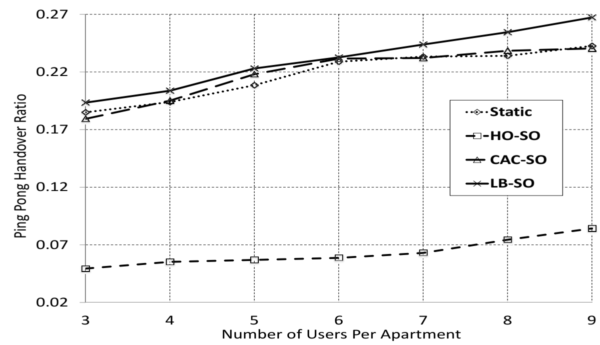
(a) HOFR performance.



(b) CDP performance.

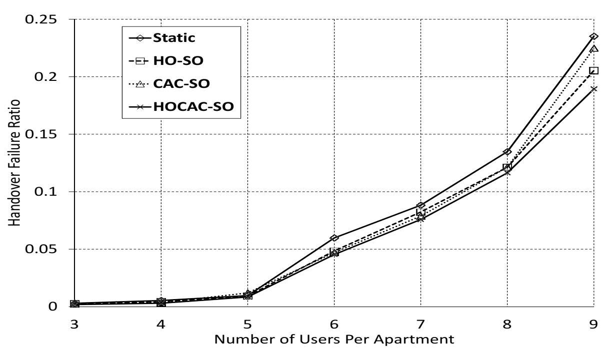


(c) CBP performance.

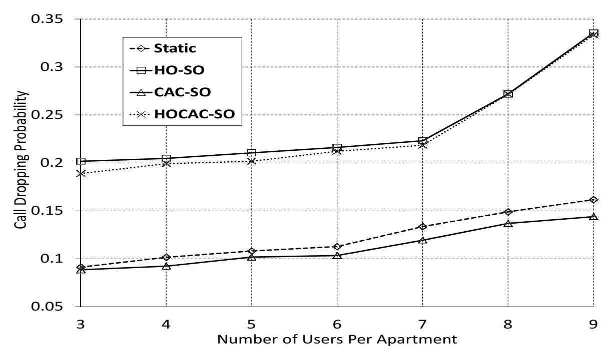


(d) PPHOR performance.

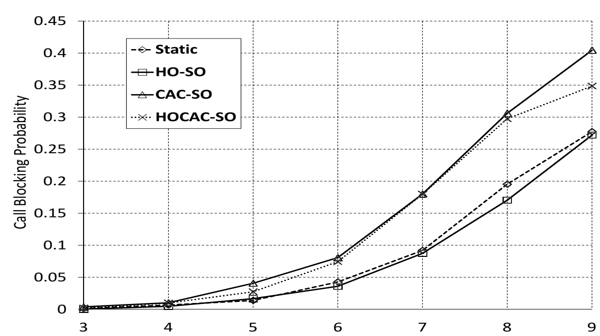
Figure 3: **Representative schemes KPIs against number of users**



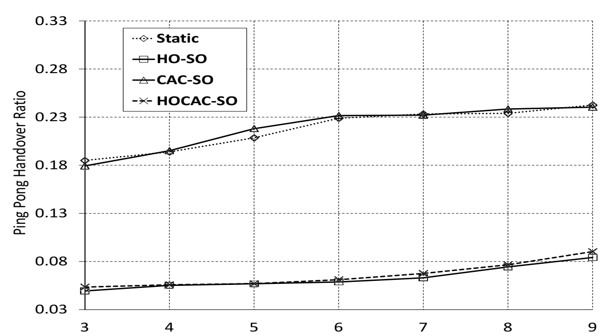
(a) HOFR performance.



(b) CDP performance.



(c) CBP performance.



(d) PPHOR performance.

Figure 4: **HOCAC-SO interaction KPIs against number of users**

4.3.2 *HOLB-SO schemes interaction*

Figure 5 shows this performance interaction in terms of HOFR, CDP, CBP and PPHOR. The HO-SO scheme attempts to limit the number of outbound handovers in order to decrease HOFR. This strategy contradicts the LB-SO scheme strategy and therefore leads the LB-SO to perform sub-optimally in terms of decreasing HOFR and CBP. However, the HO-SO scheme is now observing less HOFR, with the help of the LB-SO scheme, which leads to smaller HO-SO control parameters. This causes a slight CDP decrease and a slight PPHOR increase. In fact, PPHOR is still much lower than what it used to be when the LB-SO scheme was operating separately due to the HO-SO scheme effect.

4.3.3 *CACLB-SO schemes interaction*

Figure 6 shows this performance interaction in terms of HOFR, CDP, CBP and PPHOR. The LB-SO scheme has found channels for its outbound handover decisions reserved by the CAC-SO scheme at the target cells, which results in further decreasing HOFR. This in fact has spoiled the LB-SO scheme by allowing it to initiate even more handovers from the overutilized high power cells towards the underutilized low power cells, and therefore causing more call drops. However, the CAC-SO scheme is no longer blocking as many new calls as it used to do before. But since the CAC-SO scheme is still taking part in the process of decreasing HOFR, the CAC-SO scheme is still causing a high CBP. For the PPHOR, the LB-SO scheme still causes a high PPHOR. However, no clear interaction effect is observed in terms of PPHOR.

4.4 Discussion

In Table 2, we give the different performances a ranking. Positive numbers indicate a KPI increase in comparison to the static setting, whereas negative numbers indicate the opposite. The ranking indicates the relative performance of a certain KPI against its counterparts from the other schemes and interactions. A "zero" means that there is no clear effect demonstrated. The large bold numbers indicate when the KPI value is the lowest or the most desired.

Table 2: **Comparing the Schemes and their Interactions**

KPI	HOFR	CDP	CBP	PPHOR
HO-SO	-1	+5	-1	**-3**
CAC-SO	-1	**-1**	+3	0
LB-SO	-4	+1	**-3**	+1
HOCAC-SO	-2	+4	+2	-2
HOLB-SO	-3	+3	-2	-1
CACLB-SO	**-5**	+2	+1	+1

From this comparison, we deduce that if we are merely interested in achieving the lowest value for each KPI *independent* from its accompanying values of the other KPIs, then the following guidelines can be recommended:

- To decrease HOFR, the CAC-SO scheme and the LB-SO scheme only should be enabled. This is due to the fact that, even though all of the three handover-related self optimization schemes cause HOFR to decrease when separate, enabling both of the HO-SO scheme and the LB-SO scheme limits the LB-SO scheme's potential in terms of decreasing HOFR. This limitation or restriction negates the slight advantage introduced by the HO-SO scheme when it interacts with the CAC-SO scheme. Therefore, the best plan would be having the CAC-SO scheme and the LB-SO scheme only cooperating in terms of decreasing HOFR.

- To decrease CDP, the CAC-SO scheme only should be enabled, since it is the only scheme that decreases CDP.

- To decrease CBP, the LB-SO scheme only should be enabled. The HO-SO scheme is disabled to avoid restricting the LB-SO scheme from giving its full potential in terms of decreasing CBP. For the CBP decrease introduced by the HO-SO scheme, this decrease is in fact a side effect of the CDP increase introduced by the HO-SO scheme which should always be avoided at all costs.

- To decrease PPHOR, the HO-SO scheme only should be enabled. This is because the LB-SO scheme increases PPHOR, while the CAC-SO scheme causes the HO-SO scheme to use even lower control parameter values which triggers more ping pong handovers.

5. CONCLUSION AND FUTURE WORK

With the large number of femtocells expected to be deployed, several SON use cases have been proposed. Some of them might be monitoring related KPIs or adjusting the same control parameters. This can lead to either positive or negative interactions. In this work, we address interactions occurring between three self optimization use cases all aiming at optimizing the overall handover procedure in LTE femtocell networks. These use cases are: handover self optimization, call admission control self optimization and load balancing self optimization. Three representative schemes are elected after conducting a survey.

Using our in-house LTE-compliant simulation environment, representative schemes are verified first to meet their individual objectives. After that, mutual interaction experiments are conducted. Based on these simulation results, some guidelines are recommended which we believe can help in designing better coordination policies especially in LTE femtocell environments.

For our future work, we would consider other handover-related self optimization use cases (e.g. neighbour cell list self optimization use case). After studying the resulting interactions, we plan to develop coordination policies to fit scenarios even beyond what has been considered so far.

6. ACKNOWLEDGMENTS

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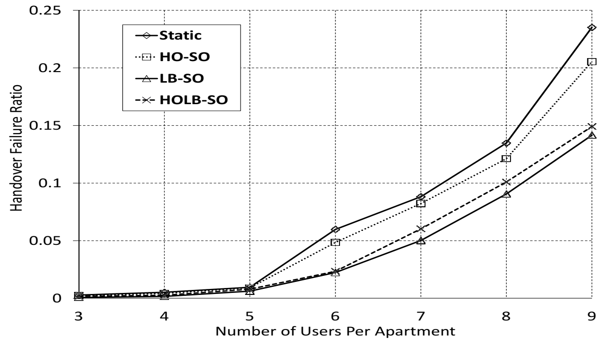
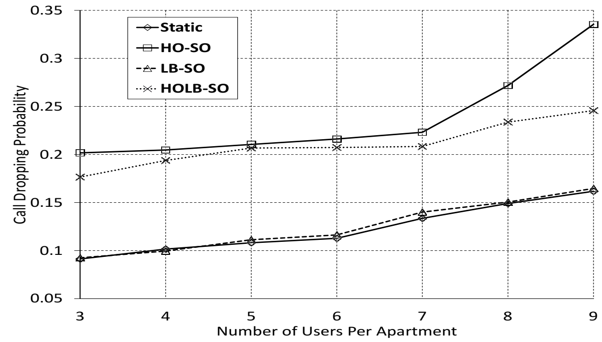
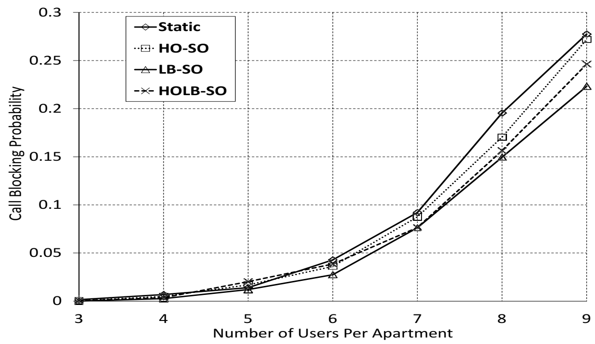


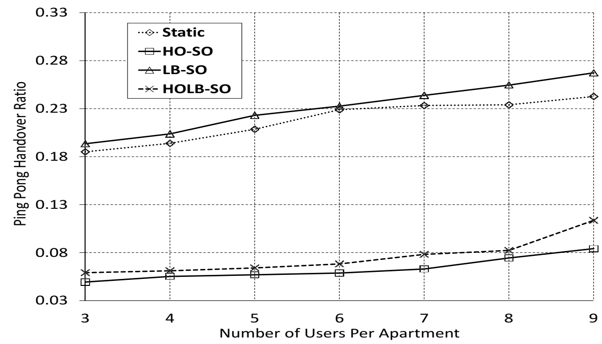
(a) HOFR performance.



(b) CDP performance.

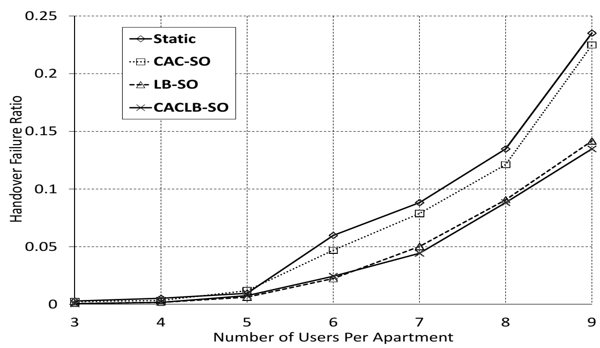


(c) CBP performance.

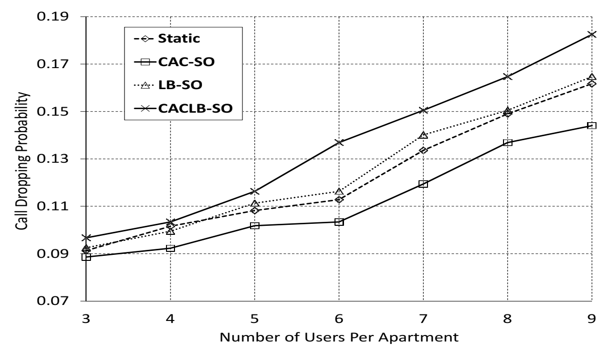


(d) PPHOR performance.

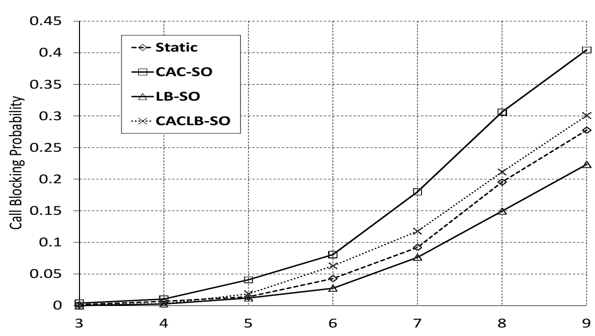
Figure 5: **HOLB-SO interaction KPIs against number of users**



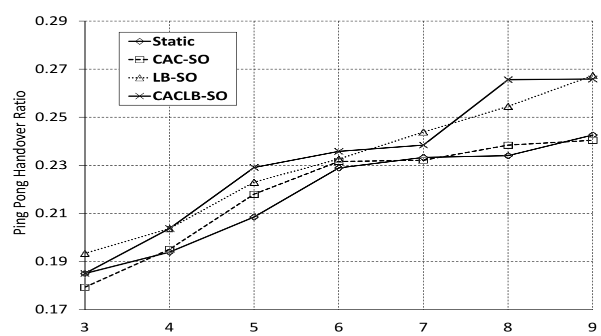
(a) HOFR performance.



(b) CDP performance.



(c) CBP performance.



(d) PPHOR performance.

Figure 6: **CACLB-SO interaction KPIs against number of users**

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