Performance Evaluation of a Coordinated Time-Domain eICIC Framework based on ABSF in Heterogeneous LTE-Advanced Networks*

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Abstract—**Enhanced Inter-Cell Interference Coordination (eICIC) is a proposed framework by the 3GPP to handle Inter-Cell Interference (ICI) in heterogeneous network (HetNet) environments. Almost-blank subframe (ABSF) is one of the time-domain techniques proposed in the eICIC framework as a candidate for deployment in LTE release 10 (LTE-Advanced). In this paper, a comprehensive ABSF framework is proposed to mitigate the interference in HetNet environments comprised of macro-cells and femto-cells. The ABSF framework proposes a tracking procedure to mark and unmark the macro-cell victim users. Also, new control message to coordinate between macro-cells and femto-cells is proposed, a novel approach to trigger the ABSF mode at aggressor Home eNBs (HeNBs), and enhancements to the macro-cell scheduling process. Finally, a novel approach for the estimation of victim users' signal-to-interference-plus-noise ratio (SINR) level during ABSF is proposed based on the well-known discrete Kalman filter. The performance evaluation results show that the proposed ABSF framework significantly improves the throughput of the macro-cell victim users with a slight degradation in the throughput of the femto-cells.**

Keywords- eICIC; ABSF; HetNet; femto-cell; Kalman filter

I. INTRODUCTION

Enhanced Inter-Cell Interference Coordination (eICIC) is a proposed framework by the 3GPP project to handle inter-cell interference (ICI) in heterogeneous network (HetNet) environments. A HetNet is a network that consists of a collection of different types of low power wireless access nodes distributed across a macro-cell. There are various types of such nodes, including micro-cells, pico-cells, relays, remote radio heads (RRHs), and femto-cells. They have different capabilities and are deployed for different targets in various environments [1]. LTE-Advanced, abbreviated as LTE-A, is the evolutionary path (Release 10 and beyond) from LTE Release 8. In order to meet the LTE-A requirements in terms of the extremely high data rates (a peak of 1 Gbps in the downlink (DL) and 500 Mbps in the uplink (UL) [2]), HetNet is one of the proposed techniques for capacity and coverage enhancements. Such scenario, however, will lead to an inevitable increase in interference levels between different nodes, which necessitates the development of new algorithms and techniques for interference coordination. The focus in this paper is on eICIC issues and techniques in a HetNet environment comprised of macro-cells and femto-cells.

In the open literature, different categories of eICIC solutions have been proposed for the mitigation of interference between macro-cells and femto-cells in HetNet environments. These solutions can be categorized as follows [3]: time-domain techniques, power control techniques, and frequency-domain techniques. ABSF (Almost Blank SubFrame) is one of the proposed time-domain techniques in the eICIC proposal [4]. We propose a comprehensive framework based on ABSF to mitigate interference between a Macro eNB (MeNB) and a Home eNB (or femto-cell) (HeNB). Throughout the paper, we refer to a user equipment (UE) served by an MeNB as an MUE, a UE served by an MeNB but experiencing high interference from an HeNB as a victim MUE (VMUE) and a UE served by an HeNB as an HUE.

A. Overview of eICIC ABSF Mechanism

In this approach, the HeNB configures some of its subframes as almost blank and hence the name ABSF. In particular, an ABSF is a subframe in which no control (PDCCH) or data (PDSCH) are transmitted; it is almost blank because some resource elements are still mapped to reference symbols (RSs) and all other resource elements are nulled. ABSFs are fully backward compatible and characterized by lack of unicast transmission on any physical channel as stated in [5]. The use of ABSF by a femto-cell thus mitigates the strong downlink interference that victim MUEs are exposed to when they are in the vicinity of this femto-cell. The MeNB schedules the transmission to those VMUEs during the ABSF to improve their throughput, and to enhance the overall performance of the network.

Although subframe blanking at femto-cells mitigates the interference between MeNB and HeNB, interference still exists due to the RSs existing in the ABSF at HeNB. Another drawback of this approach is that the throughput of the femto-cell is degraded due to the blanked subframes. The ABSF pattern is defined by the blanking rate and the location of the blanked subframe within an LTE frame. A set of available ABSF patterns for FDD and TDD deployments are defined in [6] where the blanking rate $\leq 3/8$ (for FDD) and $\leq 2/10$ (for TDD), and the patterns shall apply starting from subframe 0.

B. Summary of Contributions

The proposed ABSF framework concretely specifies the aspects related to the application of the ABSF technique in LTE-Advanced networks. The proposed framework provides:

1) A complete tracking procedure for the MUEs to mark and unmark their victim state.

2) A procedure to trigger the activation of ABSF mode in the aggressor HeNBs based on the target signal-to-interference-plus-noise ratio (SINR) for each VMUE.

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3) A communication and coordination scheme to provide cooperation between MeNB, VMUEs, and HeNBs. The framework uses existing reports in LTE such as channel-quality indicator (CQI) and Reference Signal Received Power (RSRP) reports. It is important to note that not all the reported CQI reports are taken into consideration; only measurements from the previous ABSFs are considered since the channel quality for the VMUEs varies dramatically between normal and almost blank subframes. Moreover, the CQI reports in non-ABSF subframes are used in tracking the state of the VMUE.

4) Enhancements to the scheduling scheme to provide higher priority to VMUEs during ABSFs, and to prohibit scheduling them during non-ABSFs.

5) It also provides a novel approach to estimate the SINR level of VMUEs during ABSF based on discrete Kalman filters [7].

The proposed ABSF framework is simulated using LTE-Sim [8], and the simulation results show that the proposed ABSF framework significantly improves the throughput of the macro-cell victim users, with a slight degradation in the throughput of the femto-cells. An improvement of 50% in the macro-cell throughput is achieved at some input loads, with degradation not more than 12% in the aggregate throughput of the femto-cells for the 1/8 ABSF pattern.

The rest of the paper is organized as follows: Section II provides a description of the system model. The proposed ABSF framework is discussed in Section III and Section IV contains the results of the system simulation and their discussion. Finally, conclusions are summarized in Section V.

II. SYSTEM MODEL

We consider the downlink (DL) of an LTE-Advanced HetNet environment as illustrated in Figure 1. The HetNet setup under study is comprised of one macro-cell serving M MUEs and N femto-cells each serving one HUE. We assume that the macro-cell has a coverage radius of R m, and an MeNB is centered in the cell area serving the whole macro-cell as one sector. The femto-cells are uniformly distributed in the macro-cell area and are located in B buildings, with a density of D femto-cells / km^2; each femto-cell is covered by one HeNB in CSG (Closed-Subscriber Group) mode and serves one HUE. The HUE is stationary and running a CBR application with a rate R_{max} Mbps to fully utilize the HeNB bandwidth.

The MeNB follows a Proportional Fair (PF) scheduling strategy; however, any other utility-based scheduling scheme can be used. It is assumed that X2 communication between the MeNB and HeNBs is available through a broadband connection backhaul (DSL, cable, or fiber). Another assumption is that all HeNBs deployed in the macro-cell area can execute a synchronization procedure to synchronize with the MeNB. The MeNB triggers the aggressor HeNBs through the backhaul link to operate in the ABSF mode, with a chosen ABSF pattern. The proposed ABSF framework exploits existing measurement reports such as the CQI and Reference Signal Received Power (RSRP) reports for ease of adoption. An important assumption here is that the CQI feedbacks for the SINR measurements during the ABSF are reported in the next subframe, and that the CQI feedbacks are periodic with a suitable period [9].

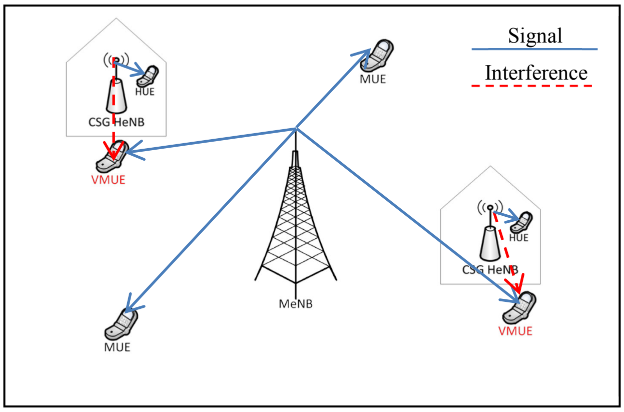

Figure 1. HetNet Environment

III. THE PROPOSED ABSF FRAMEWORK

The proposed framework is developed to assess the potential of ABSF technique in resolving interference problems in HetNet environments. It takes into consideration most of the practical aspects that might affect its deployment in realistic scenarios. The framework describes a tracking procedure to track the MUEs served by a given MeNB, and proposes a criterion to mark certain MUEs as victim users, and to put them back on the list of normal or non-victim users. Once one or more of the MUEs are marked as victims, they follow another procedure to report their measurements of the received power from the HeNBs in their vicinity. Based on the reported measurements, the MeNB executes another procedure to trigger the ABSF mode on and off in the aggressor HeNBs, the aggressor HeNBs are those reported by victim users due to their close proximity to them, and hence their strong interference level. All the proposed procedures need coordination between the MUEs, the serving MeNB, and the HeNBs. In the following subsections a detailed description of each component of the ABSF framework is presented.

A. Tracking of MUEs and Marking of Victim MUEs

The associated UEs to a macro-cell (MUEs) are moving in the cell area, when an MUE is in close proximity to an HeNB; it suffers from strong interference in the downlink as shown in Figure 1. This interference causes a drop in the MUE's SINR to very low levels therefore and it cannot receive control or data channels. The served MUEs by a given MeNB should be tracked to ensure that their SINR level is above a certain minimum. The tracked MUEs need to be marked as victims if their downlink SINR level becomes low, and a criterion for the marking scheme should be defined. The downlink interference level is the most proper criterion because the MUE is considered as a victim MUE if it suffers strong interference from adjacent femto-cells. The SINR is an effective measure for the interference level, and hence, a suggested criterion to set the MUE as a victim is to track its downlink interference level and set it as a victim if the SINR falls below certain minimum level.

Based on technical documentation in 3GPP standardization, typical values of target SINR for downlink control channels transmission are -6 dB or -4 dB [10]. However, we propose setting the SINR threshold to -3 dB to be more conservative. Hence, an MUE that measures an SINR below -3 dB (CQI feedback of 3) will be considered as a victim MUE. This may, however, include MUEs on the cell edge who may not particularly suffer from high interference but a low received signal strength due to path loss.

Those MUEs will also be dealt as victims and their SINR can be improved but only slightly.

Another issue that needs to be clarified here is when to mark an MUE as a victim. A clear answer to this question is to track the CQI feedbacks of the MUE and set it as a victim whenever its reported SINR goes below the threshold SINR. However, this degradation in the SINR could be instantaneous and might not last for a long time and marking the MUE as a victim could thus be an erroneous decision. To take this possibility into account, we propose that the tracking of a user should be during a certain predefined period. If it suffers the low SINR during this period, it can be marked as a victim user. In the proposed framework, the tracking period is set to 50 ms. This choice for the tracking period is based upon the fact that some service like VoIP is considered to be in outage if it cannot receive control data (i.e., user SINR is smaller than −4 dB) for a time interval of 200 ms [1].

The tracking procedure to mark an MUE as victim or normal depends mainly on the reported CQIs. Once the reported wideband CQI value is equal to 3, the MeNB starts the tracking procedure. The reported CQI is filtered based on the following equation:

$$\mathrm{CQI}_f[n] = \lfloor \alpha.\mathrm{CQI}[n] + (1-\alpha).\,\mathrm{CQI}_f[n-1] \rfloor \tag{1}$$

where $\mathrm{CQI}_f[n], \mathrm{CQI}_f[n-1]$ are the filtered CQI values at time instants $n, n-1$ respectively, $\mathrm{CQI}[n]$ is the reported CQI at time instant n, and α is the filter parameter and should be set to a suitable value (for example 0.2).

A given MUE is marked as a victim if its filtered CQI after the tracking period becomes 3. On the other hand, if the wideband CQI feedback from a VMUE for a regular (non- ABSF) subframe becomes greater than 3, the tracking procedure executes. Then if the filtered CQI at the end of the tracking period becomes 4 or more, the MeNB marks this MUE back as a normal MUE.

B. Activation and Deactivation of ABSF mode in Aggressor HeNBs

An aggressor HeNB is one that is located near an MUE and generating strong interference on that MUE in the downlink. The MeNB coordinates with the MUE to know which HeNB is interfering with it, and hence; it can subsequently trigger this HeNB to activate or deactivate the ABSF mode. The proposed technique in the proposed ABSF framework to trigger the ABSF mode in certain HeNBs is inspired by the handover procedure. Each active MUE marked as a victim continuously reports its measurements for the received signal power from adjacent HeNBs. The serving MeNB analyzes these reports and triggers the ABSF mode in a selected set of HeNBs. The MeNB selects and triggers those HeNBs with higher level of interference. The triggering of additional HeNBs could be repeated (if there are candidate HeNBs affecting the VMUE) until the SINR level of the VMUE during the ABSF reaches the specified target SINR. The target SINR level for each VMUE is based on its location from the MeNB where typically the cell-center MUEs target SINR is higher than that of the cell-edge MUEs.

Once an HeNB is triggered to activate ABSF mode, it follows the ABSF pattern specified in the triggering control message from the MeNB. The MeNB also starts to schedule VMUEs that are in close proximity to the triggered HeNB during the ABSF subframes. The triggered HeNBs are continuously monitored through the VMUEs reports to track their interference level, and they are triggered to deactivate the ABSF mode once the associated VMUE is marked back as a normal MUE. The ABSF pattern selection is described next.

C. Selection of the ABSF Pattern

Various ABSF patterns are available in the 3GPP eICIC proposal [6]; patterns 1/8, 2/8, 3/8 and 3/20 are available for FDD and patterns 1/10 and 2/10 are available for TDD. The MeNB triggers the aggressor HeNBs to activate or deactivate the ABSF mode of operation specifying the ABSF pattern to be followed at the triggered HeNB. The selection of the ABSF pattern is performed by the MeNB depending on a number of parameters such as the number of VMUEs, their locations in the cell (cell-center or cell-edge subscribers), and their requested services or in other words, their input load. Another parameter to be considered in the ABSF pattern selection algorithm is the impact on the performance of the aggressor HeNBs and the fairness between the VMUEs, and the served HUEs by an aggressor HeNB.

Different ABSF patterns will allow the VMUEs different interference-free bandwidths. In the 1/8 pattern, a bandwidth of ~ 12% of the triggered HeNB bandwidth is blanked to mitigate the DL interference with VMUEs in their vicinity. In pattern 3/8, around 37% of the triggered HeNB bandwidth is blanked, with a considerable degradation in its throughput. In this work, we only consider the 1/8 pattern. Exact selection of pattern should be a function of level of interference at the VMUE and traffic level at the HeNB. Our future work will tackle the issue of optimized ABSF pattern selection.

D. Coordination between MeNB, HeNB, and MUEs

The procedure to track the state of the MUEs, to trigger the ABSF mode in HeNBs, and any other procedure required to deploy the ABSF technique in LTE-A systems needs coordination between the associated network elements. Different coordination scenarios are needed: the coordination between the MeNB and its served MUEs to track their "victim" state, the coordination between them to report the aggressor HeNBs, and the coordination between the MeNB and HeNB to trigger the ABSF mode.

The proposed coordination scheme depends on some of the existing control messages like CQI feedbacks and RSRP measurement report, but in addition a new control message between the MeNB and HeNBs is proposed. The following subsections provide a description of how the existing control messages are used in the coordination scheme, and also an explanation of the new proposed control message.

1) CQI Report Control Message: The conventional CQI report message is necessary in the proposed ABSF framework; the necessity comes from the need for such measurements to track the interference level as seen at each active MUE. The tracking procedure to mark an MUE as victim or normal depends mainly on the reported CQI's, once the reported wideband CQI value is equal to 3, the MeNB starts the tracking procedure explained in section III. An essential assumption for the tracking procedure is that the CQI feedbacks are periodic with a suitable period [9].

2) RSRP Measurement Report Control Message: The RSRP measurement report control message is sent from a VMUE to its serving MeNB. The message contains a list of the VMUE neighbours (including HeNBs), each with the measured reference signal received power (RSRP). The RSRP from each one of the listed HeNBs represents the interference level seen by the VMUE from this HeNB. The measurement report is sorted in descending order such that the HeNB with the highest interference level comes first, and the MeNB triggers as many aggressor HeNBs until the SINR level of the VMUE rises to a certain target SINR during the ABSF. The RSRP measurement report is the same as regular scanning reports used for handover.

3) The ABSF Mode Triggering Control Message: The MeNB triggers the ABSF mode of operation in the selected HeNBs in the vicinity of certain VMUE. The HeNBs with the highest interference level, based on the reported measurement of the VMUE, are chosen to be ABSF-mode triggered. The number of the triggered HeNBs depends on the target SINR level for each VMUE. It is clear that this parameter will affect how many HeNBs in close proximity to a given VMUE will be triggered to operate in ABSF mode and as a consequence, the level of degradation in the throughput of these femto-cells.The ABSF mode triggering control message is sent from the MeNB to all the chosen HeNBs to operate in ABSF mode, the message contains the ABSF pattern that specifies which subframes in a given frame will be scheduled as ABSF.

E. Enhancements of the Downlink Scheduler at MeNB

Once one or more MUEs are marked as victims, the MeNB should give them higher priority to be scheduled during the ABSF, and prohibits their scheduling during non-ABSF subframes. The scheduling metric is the key to model this scheme in the downlink scheduler. At the beginning of each subframe, the scheduler selects all flows that can be scheduled. The scheduler calculates a pre-defined metric (e.g. proportional fair or best channel) for each flow that can be scheduled and assigns a sub-channel to the flow with the highest metric for this sub-channel. The metric may address different criteria such as the maximization of the cell aggregate throughput, the fairness among different MUEs, and the fulfillment of real-time services delay constraints. We present a scheme based on proportional-fairness but the ideas can be readily applied to any utility-based scheduling scheme that associates each user sub-channel combination with a metric used for the allocations.

The enhancement to the downlink scheduler in the proposed ABSF framework depends on the scaling of the scheduling metric; this scaling lets the metric meets different situation requirements. The scaled scheduling metric can be expressed as follows:

$$m_{i,j} = \beta \,.\, m_{i,j} \tag{2}$$

where $m_{i,j}$is the scheduling metric computed for UE *i* in the sub-channel j. The factor β in (2) is set to 0 for the VMUEs during non-ABSF, to any large value (for example 10) for the VMUEs during ABSF, and to 1 for normal MUEs whether in the ABSF or regular frames. For the non-victim MUEs, the scale factor is set to 1 leaving the metric computation unaffected. When ABSF is activated, the scale factor is set to a large number when computing the metric of the VMUEs during ABSFs, which provides them with higher priority to be scheduled. In non-ABSFs, the scale factor is set to 0 to prohibit the scheduling of VMUEs.

The use of ABSF patterns naturally results in dramatic variations in the interference level experienced by MUEs, and this represents a major challenge for the MeNB to conduct accurate link adaptation (the selection of the modulation and coding schemes) during the scheduling process. The scheduling decisions are strictly related to the channel quality experienced by each MUE, and hence on CQI feedback. Great attention should be given to two important points here. The first is that the CQI feedback of VMUEs just before an ABSF is not suitable for the calculation of the scheduling metric during ABSF periods. This is because the VMUE is experiencing strong interference in the subframes preceding the ABSF. However, due to the ABSF activation, this interference level is highly mitigated during the ABSF, and hence the reported CQI feedback is misleading and should not be used. This observation motivates us to develop a strategy to estimate the SINR level during an ABSF based on the reported CQI feedbacks from previous ABSF instants. One simple strategy to achieve this target; is to consider the measured SINR level for the previous ABSF as the expected SINR level for the next ABSF, but this simple strategy does not take into account the behavior of the process that governs the change of SINR level during ABSF, and the abrupt variations that may occur. Our proposed approach uses Kalman filtering to estimate the SINR level during an ABSF from the past measurements in the past ABSFs, and hence the abrupt changes in the SINR level during ABSF will be filtered. This approach will be described in detail in the following subsection.

The second point is that the CQI feedback of the non-victim MUEs in the subframe just after an ABSF is misleading since the interference level is reduced in an ABSF. This feedback does not express the channel state; hence the CQI feedbacks from the non-victim MUEs should be ignored in the subframes just after an ABSF.

F. Tracking of the SINR during ABSF using Kalman Filter

A Kalman filter is a set of recursive mathematical equations that can be efficiently used to estimate the state of a process in such a way that minimizes the mean of the squared error. The filter is very powerful as it supports the estimation of the state of a given process even if its precise nature is unknown. We propose using a Kalman filter to estimate the SINR level during the next ABSF based on the reported SINR level (via CQI feedbacks) for the past ABSF, as the process that governs the change of the SINR level during the ABSF is hard to be modeled. A complete description for the discrete Kalman filter is provided in [7].

There are two sets of equations that govern the Kalman filter estimation cycle: time update equations and measurement update equations. The time update equations predict the state of the process, and the measurement update equations correct this prediction. Using Kalman filters, the SINR level in the next ABSF is estimated based upon previous estimates of the SINR, and the last SINR measurement during the ABSF reported by the VMUE. This approach to track the SINR level is very efficient in terms of computational complexity, and it also converges very fast to an accurate estimate of the SINR level in the next ABSFs.

Let x_k be the estimated SINR during the ABSF at time instant *k*, and the measurement z_k is the reported measured SINR during time instant *k*, the process here is the estimation of the SINR level during the ABSF. The Kalman filter update cycle is governed by the linear difference equation:

$$x_k = x_{k-1} + w_{k-1} \tag{3}$$

with a measurement $z \in \Re^1$:

$$z_k = x_k + v_k \tag{4}$$

to estimate the state $x \in \Re^1$. The random variables w_k and v_k represent the process and measurement noise, respectively.

They are assumed to be independent (of each other), white, and with normal probability distributions:

$$p(w) \sim N(0, Q) \quad (5)$$

$$p(v) \sim N(0, R) \quad (6)$$

The time update equations of the SINR tracking process are given by:

$$x_k^- = x\hat{}_{k-1} \quad (7)$$

$$P^-_k = P_{k-1} + Q \quad (8)$$

The initial value for the state, which is the SINR, is set to -3 dB, the estimation process covariance Q is set to 0.1 dB, and the error covariance P is set to 0 dB.

The measurement update equations of the SINR tracking process are listed in (9) - (11)

$$K_k = P^-_k (P^-_k + R)^{-1} \quad (9)$$

$$x\hat{}_k = x_k^- + K_k (z_k - x_k^-) \quad (10)$$

$$P_k = (1 - K_k) P^-_k \quad (11)$$

In the time update stage, a new estimate for the SINR is computed, in the measurement update stage the previous estimate is corrected using the current measurement, and then this corrected estimate is projected as the estimate in the next time step. The Kalman gain K_k is the most important parameter in the Kalman filter which is used in the correction step, and is computed during the measurement stage.

IV. Performance Evaluation

In this section, the results of the simulation of the proposed ABSF framework are presented. The DL of an LTE-Advanced HetNet is simulated to test the performance improvement of the VMUEs with the application of the proposed ABSF framework. The VMUEs are uniformly distributed in the cell area and are assumed to be running CBR applications with a constant rate *R* kbps where *R* is selected according to the required input load. The parameters of the simulation scenario are provided in TABLE **I**. The proposed ABSF framework is simulated using LTE-Sim [6].

TABLE I. Parameters of the Simulation Scenario

Parameter	Value
System	HetNet in LTE-Advanced, deployment centered at 2000 MHz, with a carrier bandwidth = 5 MHz
Macro-cell	Cell with a radius of 500 m, and ~0.65 km^2 cell area, the eNB is centred in the cell area with omnidirectional antenna
Femto-cells	40 CSG femto-cells in 20 buildings uniformly distributed in the cell area with a density of ~60 femto-cell / km^2. Each femto-cell is serving one HUE and is fully loaded, and therefor utilizing all subcarriers.
Frequency Reuse	3
Duplex Technique	FDD
Scheduling Scheme	Modified Proportional Fair
Macro-cell Subscribers	10 MUEs uniformly distributed in the cell area with a CBR application, the CBR application has a varying rate from 50 kbps to 700 kbps for each MUE.
Femto-cell Subscribers	1 stationary HUE for each femto-cell, running a CBR application with a rate of 7 Mbps.
ABSF pattern	1/8
Simulation Aspects	Simulation time 100 secs, with 10 different realizations.

A. Throughput of the Macro-cell

In Figure 2, the throughput of the macro-cell with and without ABSF mode activation is reported. As it can be seen, the macro-cell throughput is highly improved in the ABSF mode reaching 50% in some cases. The improved throughput is for the macro-cell UEs, which fall in a victim state most of the time, Figure 3 shows the significant improvement of the VMUEs throughput in the ABSF mode with regard to non-ABSF mode of operation.

B. Aggregate Throughput for the Femto-cells

Figure 4 reports the throughput of the femto-cells, which is shown to have decreased due to the muting of the ABSFs. Since the chosen ABSF pattern is 1/8, the decrease in the throughput is less than 12% as expected.

C. Estimated SINR during ABSF using Discrete Kalman Filter

In Figure 5, the SINR during ABSF is significantly improved due to the triggering of ABSF mode at the aggressor HeNBs, the SINR of a given VMUE during ABSF is estimated from previous CQI feedbacks for ABSF, the estimation of the SINR is performed using the discrete Kalman filter and converges rapidly to the exact measurements with 2 or 3 iterations at most. The fast response and accurate tracking of the SINR by the Kalman filter are illustrated in Figure 6.

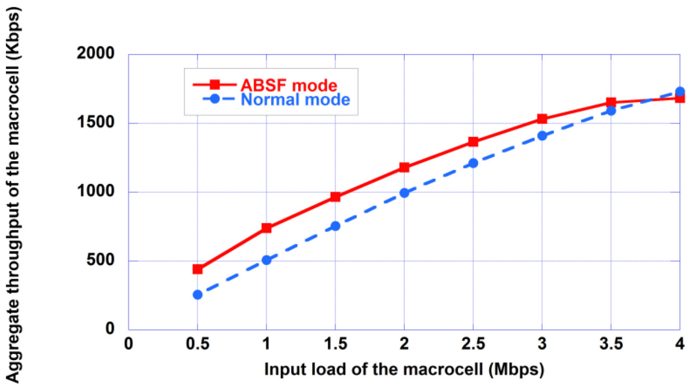

Figure 2. Aggregate throughput of the macro-cell (10 MUEs, 5 victims and 5 normal).

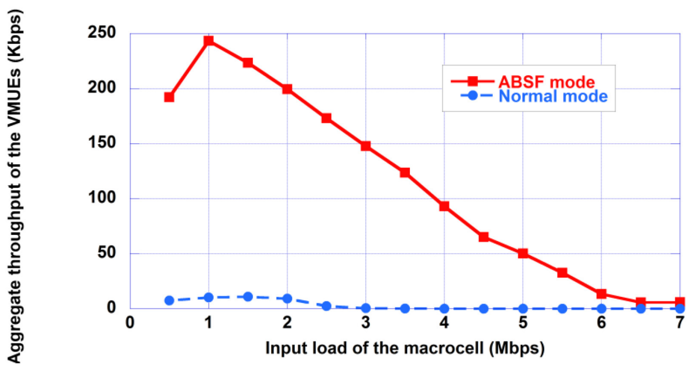

Figure 3. Aggregate throughput of the VMUEs at the macro-cell.

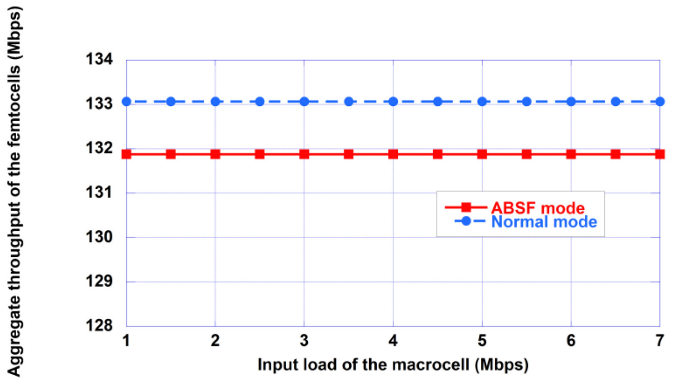

Figure 4. Aggregate throughput of the femto-cells.

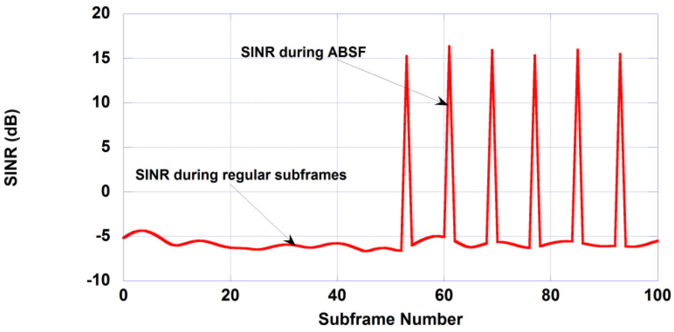

Figure 5. SINR for a VMUE during ABSF and normal subframes

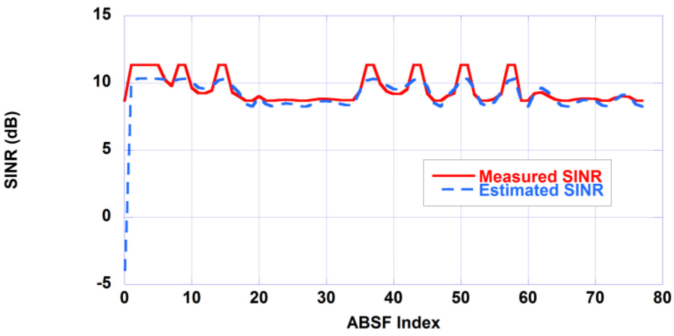

Figure 6. Fast response and accurate tracking of the SINR using Kalman filter.

V. CONCLUDING REMARKS

A comprehensive ABSF framework is proposed to cover the aspects concerning the deployment of ABSF technique in LTE-Advanced HetNet environments. The framework uses existing control messages (CQI feedbacks and RSRP reports) and proposes a new control message (ABSF mode triggering).

Novel procedures and techniques are proposed to track the MUEs and maintain their victim state, to ease the coordination between network nodes (MeNB, MUEs, and HeNBs), to enhance the scheduling scheme, and to estimate the SINR level of the VMUEs during ABSF. The SINR estimation procedure is based on the well-known discrete Kalman filter.

The performance evaluation of the proposed framework shows that the throughput of the VMUEs is improved significantly with a slight degradation in the throughput of the HeNBs. The simulation shows also that the application of the discrete Kalman filter in the SINR estimation procedure is highly efficient providing rapid convergence with 2 or 3 iterations at most. The proposed approach to estimate the SINR level during the ABSF can be used in other situations due to its computational efficiency and implementation simplicity. One of the candidate applications for this approach is to reduce the number of CQI feedbacks from a given UE, and estimate the CQI during a subframe based on the previously reported measurements of this UE.

Future work will focus on developing a scheme for the ABSF pattern selection and to propose an integrated ABSF-PC (power control) scheme and evaluate its performance.

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