ABSF Offsetting and Optimal Resource Partitioning for eICIC in LTE-Advanced: Proposal and Analysis using a Nash Bargaining Approach

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Abstract—Almost-blank subframe (ABSF) is a time-domain technique, proposed by the 3GPP to handle Inter-Cell Interference (ICI) in heterogeneous network environments (HetNet). We consider a HetNet environment comprised of a macro-cell and femto-cells distributed across the macro-cell area. We propose a novel approach, called ABSF offsetting, to reduce the blanking rate at the femto-cells while preserving the required optimal blanking rate at the macro-cell. We also study the problem of optimal resource partitioning and offset assignment in the ABSF mode. The proposed solution for the problem is based on multistage Nash bargaining. The performance of the optimal resource partitioning, and ABSF offsetting is evaluated through simulations. The results show that the throughput of the macro-cell is improved, while the degradation in the aggregate femto-cell throughput is reduced due to the reduction in the blanking rate due to offsetting. The simulation results also demonstrate the fairness of the ABSF offsetting with the fairness index approaching 1 among the macro-cell UEs at low loads.

Keywords—eICIC; ABSF; HetNet; femto-cells; Nash Bargaining; ABSF Offsetting

I. INTRODUCTION

A heterogeneous network (HetNet) framework is one of the proposed solutions to achieve very high rates in LTE-Advanced. A HetNet is a network comprised of many different wireless network nodes with different features, capabilities, and targets [1]. These nodes are distributed across the coverage area of a macro-cell, and are allocated the same licensed spectrum allocated to the macro-cell, to increase the area spectral efficiency of the network [2]. Examples of these network nodes are femto-cells, pico-cells, relays, and remote radio heads (RRHs). In this paper the focus is the HetNet comprised of macro-cell and femto-cells. Throughout the paper, we refer to a Macro eNB as MeNB, a Home eNB (or femto-cell) as HeNB, a UE served by an MeNB as MUE, a UE served by an HeNB as VMUE, and a UE served by an MeNB but suffering badly from interference generated by a nearby HeNB as victim MUE or VMUE for short, and a UE served by an HeNB as HUE.

The most limiting factor for the deployment of HetNet is interference [2]. As the deployment of femto-cells is operator independent; the unplanned deployment of femto-cells is a basic feature for them, and hence the femto-cells will be a source of strong and unpredictable interference. Enhanced Inter-Cell Interference Coordination (eICIC) is a proposed framework by the 3GPP project to handle the ICI in HetNet environments. The framework proposes different solutions for the mitigation of the interference between macro-cells and femto-cells, the solutions can be categorized to: time domain, power control, and frequency domain techniques [1]. ABSF is one of the proposed time domain techniques in the eICIC framework [3]. In [4] we proposed a comprehensive framework based on ABSF to mitigate interference between an MeNB and HeNBs located in its coverage area.

In this paper we propose an innovative concept called ABSF offsetting to reduce the required blanking rate at aggressor HeNBs. In ABSF offsetting, an aggressor HeNB is configured to operate in ABSF mode with a certain blanking rate, and it doesn’t start blanking at subframe 0 as defined in [5], but starts blanking at an offset. The ABSF blanking rate and the offset of blanking forms our new proposal for the definition of an ABSF pattern. The parameter selection for the ABSF offsetting is performed via the application of multistage Nash bargaining in the context of optimal resource partitioning.

II. THE PROPOSED ABSF OFFSETTING SCHEME

A. System Model

The investigated system is the DL of an LTE-Advanced HetNet environment. The simulated HetNet consists of a macro-cell serving \(N\) MUEs and \(P\) femto-cells each serving one HUE. Denote by \(N_p\) and \(N_m\) the number of VMUEs and the normal number of MUEs, respectively. We assume the macro-cell has a coverage radius of \(R\) km, and an MeNB is centered at 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 is assumed to run a CBR application with a rate \(R_{\text{max}}\) Mbps.

The MeNB follows a Modified Proportional Fair (PF) scheduling strategy [4]. It is assumed that X2 communication between the MeNB and HeNBs is available through a broadband connection backhaul. Another assumption is that all HeNBs deployed in the macro-cell area can execute a synchronization procedure to synchronize with the MeNB. So, the system models a managed femto-cell environment.

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B. ABSF Offsetting

In this paper, we propose an innovative concept called ABSF offsetting. The ABSF offsetting is inspired by the fact that a VMUE is always suffering a high interference from the nearby aggressor HeNBs, whereas other aggressor HeNBs who are located in a distant point far from that VMUE has a very small interference footprint on it. Hence there is no need to force the entire aggressor HeNBs in the macro-cell area to operate in the ABSF mode with the same pattern required by the macro-cell. This implies that it is possible to group the VMUEs in a given macro-cell such that each group includes the VMUEs in the same vicinity. The area containing the adjacent VMUEs, along with the aggressor HeNBs interfere aggressively with them is called high interference area (HIA). Each HIA will include some of the VMUEs; hence there is no need to blank the subframes at the aggressor HeNBs existing in this HIA with a high blanking rate. This means that the aggressor HeNBs in each HIA may start blanking with a reduced blanking rate that depends on how many VMUEs are located in that HIA.

In this proposal the triggered aggressor HeNB will be assigned an ABSF pattern with a reduced blanking rate, and with an offset associated with the reduced blanking rate. The offsetting of ABSF patterns means that the start of blanking does not necessary start at subframe 0, and it may start at an offset 1, 2, or more. The offset 0 means that the blanking starts at subframe 0 and the offset 1 means that the blanking starts at subframe 1, and so on.

We illustrate the concept by the following motivating example. Consider a scenario with 20 active MUEs uniformly distributed in the macro-cell area. Assume that 10 of them are victims, and they are located in 4 different HIA. A coalition of 5 VMUEs exists in HIA1, both HIA2 and HIA3 contains 2 VMUEs, and 1 VMUE is located at HIA4. The scenario is presented in Figure 1. Based on the results that will be derived in the next section, the appropriate FDD ABSF pattern to partition the resources between the VMUEs and the normal MUEs is 2/8, and the reduced ABSF patterns assigned for each HIA is 2/8, 1/8, 1/8, and 1/8 respectively. The blanking rate assuming no ABSF offsetting is 3/8. However the average blanking rate of the aggressor HeNBs in the case of ABSF offsetting becomes 1.25/8. This achieves a gain of 1.75/8 improvement in the throughput of the aggressor HeNBs. The question now is whether this improvement in the aggressor HeNBs throughput has an impact on the throughput of the macro-cell. The delightedly surprising answer is NO. The ABSF offsetting magically achieves the same effective blanking rate of 3/8 for the macro cell victim users which are not aware how the offsetting is operated in HeNBs. The reduced blanking rates associated with an offset for each HIA will result in that the macro-cell experiencing an effective blanking rate of 3/8 while the blanking rate in the aggressor HeNBs is reduced compared to the no offsetting case. The optimal ABSF pattern selected at the MeNB, the reduced ABSF pattern, and the offset associated to each HIA for the motivating example are illustrated in Figure 1. The offsets of the reduced blanking rates for each HIA are selected in a round robin manner. The HIAs are sorted in descending order relative to the coalition size, i.e. the number of VMUEs in a coalition, and then each HIA is assigned an offset in turn.

The resource partitioning between normal MUEs and VMUEs influences the throughput of the macro-cell, and the fairness between its UEs. Hence the ABSF pattern should be selected carefully. ABSF offsetting implies a second stage of resource partitioning. The assigned ABSF amount for the VMUEs in the first stage of resource partitioning is repartitioned again between VMUEs’ coalitions in different HIAs. This leads to the reduction of the blanking rate in each HIA based on how many VMUEs exist in that HIA. We propose the modeling of this multistage resource partitioning as a multistage Nash bargaining problem. The analysis of the resource partitioning via multistage Nash bargaining, forming the coalitions between the VMUEs to find the HIAs, and the selection of ABSF offsetting parameters will be discussed in the next section.

III. OPTIMAL ABSF PATTERN AND OFFSET SELECTION

In our model for the resource partitioning between normal MUEs and VMUEs, the resources are partitioned in two stages. In the first stage all the MUEs of the macro-cell form two coalitions, one for the normal MUEs and the other for the VMUEs. A bargaining starts between the two coalitions to partition the resources between them, and to specify the optimal and fair blanking rate. As this stage ends, the second stage of bargaining starts between the VMUEs themselves. In the second stage of bargaining the VMUEs are formed in coalitions each includes the VMUEs in a given HIA. The bargaining in this stage yields to the partitioning of resources again and hence the reduction of the blanking rate associated to each HIA. In this stage of resource partitioning, each coalition is assigned a part of the ABSF amount. There may be a resource partition that is shared partially or completely between two coalitions, and thus the new resource partitions in the second level of bargaining may be overlapping. Hence each reduced blanking pattern will be associated with an offset to guarantee that the effective blanking rate seen by the macro-cell is the optimal and fair blanking rate decided in the first stage of bargaining.

Bargaining problems represent situations where two or more individuals have conflicting interests, but with the possibility of concluding a mutually beneficial agreement. An N-person bargaining problem is a pair \((\delta, \mathcal{D})\) that can be described as follows: Let \(\mathcal{N} = \{1, 2, ..., N\}\) be the set of players in a bargaining of a cooperative game. Let \(\delta\) be a closed and convex subset of \(\mathbb{R}^N\) to represent the
set of feasible resource allocations that the players can get if they cooperate. Let \( d_i \) be the minimal resource allocation that the \( i \)-th player would expect; otherwise, he will not cooperate. Define \( d = (d_1, \ldots, d_N) \) as the disagreement point at which no agreement is formed between the players to cooperatively partition the resources [6].

A bargaining solution can be seen as the mutual agreement on some utility point \( v = (v_1, \ldots, v_N) \) from the convex feasible set \( \mathcal{S} \) for resource allocation utility; the \( N \) players cooperate in order to achieve a solution outcome \( \varphi(\mathcal{S}, d) \) which is component-wise greater than the disagreement point \( d \in \mathcal{S} \) [6]. Nash solution for the bargaining problem is based on an axiomatic approach. There are four basic axioms stated by Nash for his solution to the bargaining problem [7]. The Nash bargaining solution (NBS) that satisfies the four axioms can be defined as follows:

\[
\varphi(\mathcal{S}, d) = \max_{v \in \mathcal{S}, \sum v_n \leq 1} \prod_{n=1}^{N} (v_n - d_n) \tag{1}
\]

As observed in [8], the proportional fairness is a special case of the NBS fairness; when the disagreement point \( d = 0 \) \( (d_i = 0 \ \forall \ i) \), the proportional fair operating point can be found by solving:

\[
\max_{v \in \mathcal{S}, \sum v_n \leq 1} \sum_{n=1}^{N} \log v_n \tag{2}
\]

Since \( \log \prod_{n=1}^{N} v_n = \sum_{n=1}^{N} \log v_n \), and hence the NBS is proven to be both optimal (Pareto-optimality) and fair.

One of the main branches of cooperative game theory is coalitional game theory [9]. In coalitions, the players instead of negotiate individually, they negotiate as groups (or coalitions) with unified interests and common benefits.

A. Problem Formulation

The ABSF pattern selection problem is modeled as a bargaining between two coalitions: the normal MUEs and the victim MUEs. Let \( N_d \) and \( N_v \) be the number of normal MUEs and the number of VMUEs in a given macro-cell respectively. The negotiation between the two coalitions will occur in the MeNB as a market to partition the available resources where the two groups attempt to agree on a resource partitioning that is fair and optimal. Let \( a \) be the blanking rate defined as the amount of ABSF per pattern period. Let \( U_n \) and \( U_v \) denote the normal MUEs sub-utility in non-ABSF, and the VMUEs sub-utility in ABSF respectively, \( d_n \) and \( d_v \) denotes the disagreement utility of the normal MUEs and VMUEs respectively. The cell-wide aggregate utility is defined as the product:

\[
U_{\text{MeNB}} = (U_n - d_n)(U_v - d_v) \tag{3}
\]

The NBS can then be found by maximizing the cell-wide aggregate utility \( U_{\text{MeNB}} \) achieved by the mutual maximization of the normal MUEs and the VMUEs subutilities \( U_n \) and \( U_v \). This operating point \( \varphi(\mathcal{S}, d) \) can be found by solving:

\[
\varphi(\mathcal{S}, d) = \max_{U_n \in \mathcal{S}, U_v \in \mathcal{S}} U_{\text{MeNB}} = \max_{U_n \in \mathcal{S}, U_v \in \mathcal{S}} (U_n - d_n)(U_v - d_v) \tag{4}
\]

where \( \mathcal{S} \) is the feasible set for resource allocation utility, \( U = (U_n, U_v) \) is the subutilities point, and \( d = (d_n, d_v) \) is the disagreement point. The subutilities \( U_n \) and \( U_v \) can be defined as follows:

\[
U_n = \prod_{i=1}^{N_n} (1-a) \cdot \frac{G(N_n)}{N_n} \cdot r_i \tag{5}
\]

\[
U_v = \prod_{j=1}^{N_v} a \cdot \frac{G(N_v)}{N_v} \cdot r_j \tag{6}
\]

where \( r_i \) and \( r_j \) are the average rates for a normal MUE \( i \) and a victim MUE \( j \) respectively. The terms \( G(N_n) \) and \( G(N_v) \) represent multiuser diversity gains which could be calculated as \( G(N_n) = \sum_{i=1}^{N_n} \frac{1}{i} \) and \( G(N_v) = \sum_{i=1}^{N_v} \frac{1}{i} \) [10]. The rates \( r_i \) and \( r_j \) could be obtained via large-scale wideband received SINRs. It is worth mentioning that \( r_i \) is the average link rate for a normal MUE in the non-ABSF, therefore, it is scaled with \((1-a)\) (since this rate will only be attainable at \((1-a)\) of the subframes), and \( r_j \) is the average link rate for a victim MUE in the ABSF thus scaled with \( a \).

Consider the case with elastic traffic where the application traffic uses TCP as the transport protocol. TCP typically attempts to achieve the maximum rate allowed by the system, and the minimum rate that can be accepted by any user may reach zero. Hence we can set the disagreement point as \( d = 0 \). The cell-wide aggregate utility in this case can be expressed as \( U_{\text{MeNB}} = U_n U_v \), and at this special case, we can find the operating point of the Nash bargaining problem through finding the proportional fair operating point, and this can be achieved by solving:

\[
\max_{U_n, U_v} (\log U_n + \log U_v) \tag{7}
\]

Problem (4) then becomes:
The target is to find $\alpha$ that maximizes \( \sum_{i=1}^{N_n} \log \left( \frac{G(N_n)}{N_n} \cdot r_i \right) + N_v \times \log(1 - \alpha) \), and since the term $\sum_{i=1}^{N_n} \log \left( \frac{G(N_n)}{N_n} \cdot r_i \right)$ and the term $\sum_{j=1}^{N_v} \log \left( \frac{G(N_v)}{N_v} \cdot r_j \right)$ are independent of $\alpha$, then to maximize (8):

\[
\frac{d(\cdot)}{d\alpha} = 0
\]

\[
\frac{-N_n + N_v}{1 - \alpha} + \frac{N_v}{\alpha} = 0
\]

The value of $\alpha$ that maximizes (8) is therefore:

\[
\alpha = \frac{N_v}{N_n + N_v}
\]

The derived result seems very intuitive and is expected by common sense. The results show that the optimal and fair amount of ABSF should be proportional to the number of VMUEs scheduled in ABSF relative to the number of active MUEs. We consider only the patterns $1/8$, $2/8$, and $3/8$ for FDD mode, and $1/10$ and $2/10$ for TDD mode. The ABSF pattern selection depends mainly on the result derived in (11) and is given by:

\[
l_{\text{FDD}} = \max(\min(\alpha, 1/8, 2/8, 3/8), 1)
\]

\[
l_{\text{TDD}} = \max(\min(\alpha, 1/10, 2/10), 1)
\]

where $l_{\text{FDD}}$ is the ABSF pattern index for FDD patterns, $l_{\text{TDD}}$ is the ABSF pattern index for TDD patterns, and the operator $[\cdot]$ indicates rounding the value. The ABSF pattern indices in the FDD mode are 1, 2, and 3 for the blanking rates $1/8$, $2/8$, and $3/8$ respectively. In the TDD mode the ABSF pattern indices are 1 and 2 for the blanking rates $1/10$ and $2/10$ respectively.

The second stage of bargaining occurs between coalitions formed from the VMUEs, each coalition is located in a HIA. Let the number of HIAs in the coverage area of the macro-cell be $H$, and let the number of VMUEs in HIA $i$ be $N_i$ such that $\sum_{h=1}^{H} N_h = N_v$. In the second stage of bargaining the assigned resources for the VMUEs will be partitioned again resulting in operating each HIA with a reduced blanking rate (except in extreme cases where all VMUEs exist in one coalition). Let $\beta_i$ be the portion of resources that is assigned to HIA $i$, such that $\sum_{h=1}^{H} \beta_h = 1$. By modeling the problem as a Nash bargaining problem with a set of $H$ coalitions similar to bargaining in the first stage, the problem becomes:

\[
\max_{i \in \mathbb{H}} \sum_{h=1}^{H} \left( N_h \times \log(\beta_h) + \sum_{i=1}^{N_i} \log \left( \frac{G(N_i)}{N_h} \cdot r_h \right) \right)
\]

The objective is to find the values $\beta_1, \beta_2, ..., \beta_h$ that maximize the VMUEs aggregate utility, by substituting:

\[
\beta_h = 1 - \beta_1 - \beta_2 - ... - \beta_{h-1}
\]

and taking partial derivatives relative to $\beta_1, \beta_2, ..., \beta_h$, and equating the to 0, we get

\[
\frac{N_i}{\beta_i} - \frac{N_h}{1 - \beta_1 - \beta_2 - ... - \beta_{h-1}} = 0 \quad \forall i
\]

By solving the above set of equations we can find that:

\[
\beta_i = \frac{N_i}{N_v} \quad \forall i
\]

and hence, the reduced ABSF pattern index in the case of FDD mode can be calculated using:

\[
l_i = \max(\lfloor \beta_i \cdot l_{\text{FDD}} \rfloor, 1) \quad \forall i
\]

or in the TDD mode using:

\[
l_i = \max(\lfloor \beta_i \cdot l_{\text{TDD}} \rfloor, 1) \quad \forall i
\]

The derived result is analogous to the result derived in (11) - (13), and provides a rule of thumb for repartitioning of the resources between the VMUEs in different HIAs. A final note to mention here is that the ABSF pattern index is calculated in (12), (13) via a rounding function to select the blanking rate with the minimum distance to one of the available blanking rates. This is because the values of $\alpha$ do not always coincide with the available blanking rates due to their discrete nature. While the reduced blanking index in (18), (19) is
calculated using ceiling function. The reduced blanking rates for different HIAs may overlap; and hence the same resource may be shared between VMUEs in those HIAs. When calculating the reduced blanking rate we ceil to the nearest higher blanking rate to compensate for this expected overlap.

The coalition formation of the VMUEs is performed in the MeNB, and the procedure is listed in Algorithm 1. The main idea is based on that each VMUE will report a set of interfering HeNBs affecting its downlink to the MeNB [4]. The MeNB will then execute a set intersection based algorithm to group the VMUEs. Initially the first HIA is comprised of the VMUE \( v_1 \), and the set of reported HeNBs from that VMUE. A loop starts over the remaining VMUEs, if an aggressor HeNB is reported from the current VMUE, and is reported already from any of the previously grouped VMUEs, a coalition is formed from this VMUE and the VMUE reporting the same aggressor HeNB, otherwise a new coalition is formed, and so forth.

IV. PERFORMANCE EVALUATION

In this section, the results of the simulation of the ABSF offsetting proposal and optimal resource partitioning algorithm are presented. The DL of an LTE-Advanced HetNet is simulated to investigate the performance improvement of the macro-cell aggregate throughput, the VMUEs aggregate throughput, and the ABSF-mode triggered HeNBs throughput. The simulation also investigates the fairness of the proposed algorithms. 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 algorithms are simulated using LTE-Sim [11].

### Algorithm 1 HIA Grouping and Coalition Forming Algorithm

1: Define
   \( V \): the set of all VMUEs in a given MeNB \( V = \{ v_1, v_2, ..., v_N \} \)
2: \( H_i \): the set of aggressor HeNBs reported by VMUE \( i \)
3: \( C \): the set of VMUEs' coalitions \( C = \{ C_1, C_2, ..., C_M \} \)
4: \( Z \): the set of aggressor HeNBs in each HIA \( Z = \{ Z_1, Z_2, ..., Z_M \} \)

2: Initialize:
   \( C_1 = \{ v_1 \}, Z_1 = H_1, grouped = false \)
3: for \( n = 2 \) to \( N \)
4:   for \( m = 1 \) to \( M \)
5:     if \( H_i \cap Z_m \neq \emptyset \)
6:       \( C_m = C_m \cup \{ v_n \}, Z_m = Z_m \cup H_n, grouped = true \)
7:     break loop for \( m \)
8:   end if
9: loop \( n \)
10: if (not \( grouped \))
11: \( C_{m+1} = \{ v_n \}, Z_{m+1} = H_n \)
12: end if
13: loop \( n \)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td>HetNet in LTE-Advanced with center frequency of 2000 MHz and a carrier bandwidth of 5 MHz</td>
</tr>
<tr>
<td>Macro-cell</td>
<td>Cell with a radius of 500 m, the eNB is centred in the cell area with omni-directional antenna</td>
</tr>
<tr>
<td>Femto-cells</td>
<td>40 CSG femto-cells in 40 buildings uniformly distributed in the cell area with a density of ~60 femto-cell/km². Each femto-cell is serving one HUE and is fully loaded, and therefor utilizing all subcarriers.</td>
</tr>
<tr>
<td>Duplex Technique</td>
<td>FDD</td>
</tr>
<tr>
<td>Scheduling Scheme</td>
<td>Modified Proportional Fair [4]</td>
</tr>
<tr>
<td>Macro-cell UEs</td>
<td>12 MUEs uniformly distributed in the cell area with a CBR application. The CBR application has a varying rate from 100 kbps to 650 kbps for each MUE. 6 of the MUEs are VMUEs and they are positioned such that each 2 VMUEs are located in the same HIA</td>
</tr>
<tr>
<td>Femto-cell UEs</td>
<td>1 stationary HUE for each femto-cell.</td>
</tr>
</tbody>
</table>

A. Throughput of the Macro-cell

The investigated simulation scenario states that the macro-cell serves 12 MUEs, 6 of which are VMUEs. The application of the ABSF pattern selection algorithm will select the ABSF 3/8 pattern as the optimal and fair blanking rate. In Figure 2, we report the macro-cell throughput for different ABSF patterns and including the proposed ABSF offsetting scheme as function of the total macro-cell input load.
The results show that the macro-cell aggregate throughput of the ABSF pattern 3/8 is the highest as expected whereas the performance of the ABSF offsetting scheme is identical.

**B. Aggregate Throughput for the VMUEs**

Figure 3 shows that the aggregate throughput of the VMUEs improves significantly with higher blanking rate with the highest rate achieved with the 3/8 blanking rate as selected by the ABSF pattern selection algorithm. The results also show that the effect of ABSF offsetting on the VMUEs throughput is almost negligible.

**C. Aggregate Throughput for the Femto-cells**

Figure 4 shows that the throughput of the triggered femto-cells to operate in ABSF-mode gets decreased with higher blanking rate, the decrease in the throughput is relative to the amount of blanked subframes, the ABSF offsetting highly compensate the decrease in the aggressor HeNBs throughput, and it gives higher throughput to the HUEs in ABSF-mode triggered femto-cells without affecting the throughput of the macro-cell MUEs, both normal MUEs and victim MUEs.

**D. The Fairness Index for the Macro-cell UEs**

Figure 5 shows that the Jain’s fairness index [12] of the macro-cell UEs is highly improved with the application of ABSF mode. The fairness index with non-ABSF is 50% which is expected as half of the MUEs are victims in the simulated scenario, and with non-ABSF their throughput is almost zero. The results show that fairness index is improved with higher blanking rates, and it reaches its maximum value with the optimal resource partitioning blanking rate selected by the ABSF pattern selection algorithm for this scenario which is 3/8. The fairness index with the application of the ABSF offsetting scheme is the same as what is achieved with ABSF only. The ABSF offsetting increases the throughput of the triggered HeNBs as a result to the reduction of the blanking rate in each HIA, and hence it achieves a more efficient and fair equilibrium point between normal MUEs, VMUEs, and HUEs.

**V. CONCLUDING REMARKS**

In this paper we propose a novel algorithm called ABSF offsetting. In ABSF offsetting the VMUEs are grouped in HIAs, and the aggressor HeNBs in each HIA are assigned a reduced blanking rate with an offset, the offset is the subframe to start blanking at. The performance evaluation results show that the ABSF offsetting preserves the performance of the macro-cell as in the equivalent ABSF pattern, however it significantly improves the performance of ABSF-mode triggered HeNBs. Also, fairness is improved. Future work will focus on proposing an integrated ABSF-PC (power control) scheme and evaluate its performance.

**REFERENCES**


Figure 2. Aggregate throughput of the macro-cell (12 MUEs, 6 victims and 6 normal).

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

Figure 4. Aggregate throughput of the femto-cells.

Figure 5. The fairness index of the macro-cell UEs.