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

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Agenda

- HetNet, eICIC, and ABSF - An Introduction
- Our Proposed ABSF Framework - Background
- ABSF Offsetting
- The Optimal ABSF Pattern Selection – A Nash Bargaining Approach
- The Reduced ABSF Patterns and Offset Selection
- Performance Evaluation
- Conclusions and Future Trends
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HetNet, eICIC, and ABSF

An Introduction
HetNet Environments
eICIC Framework

Time Domain

Power Control

Frequency Domain

eICIC
eICIC Framework

- Lightly-Loaded Subframe
- Symbol Muting
- Almost Blank Subframe
- Consecutive Subframe Blanking

Time Domain

ABSF
ABSF Technique

- Almost Blank SubFrame

Figure from [3GPP TSG RAN WG1, R1-104661,] “Comparison of Time-domain eICIC Solutions”

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ABSF Technique

- Almost Blank SubFrame

Figure from [3GPP TSG RAN WG1, R1-103264,] “Performance of eICIC with Control Channel Coverage Limitation”
ABSF Patterns (FDD mode)

- 1/8 Pattern

- 2/8 Pattern

- 3/8 Pattern

- 3/20 Pattern
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Our Proposed ABSF Framework
A Background
The Proposed ABSF Framework

- VMUEs Tracking
- Aggressor HeNBs Identification
- Prioritized Scheduling
- SINR Tracking during ABSF (Kalman Filter)
- HetNet Nodes Coordination
The Proposed ABSF Framework


- The framework provides:
  - A tracking algorithm to identify the victim macro UE’s
  - An algorithm to identify the aggressor Home eNBs
  - A coordination scheme between the HetNet nodes
  - An algorithm based on Kalman filter to track the SINR of the victim MUEs during the ABSF
  - A modification to the scheduling scheme to prioritize scheduling the resources to victim MUEs during the ABSF
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ABSF Offsetting
ABSF Offsetting Concept

- ABSF Offsetting
  - A novel approach to reduce the femto-cells throughput degradation due to ABSF.
  - The ABSF blanking normally starts at subframe 0
  - The ABSF offsetting means that ABSF blanking may start at an offset, i.e. at a subframe other than subframe 0.
  - Offset 0, 1, or 2 means the blanking starts at subframe 0, 1 or 2 respectively
ABSF Offsetting Concept

VMUs are scheduled here

ABS 1/8: 0

ABS 1/8: 1

ABS 1/8: 2

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ABSF Offsetting Procedure

1. ABSF Pattern Selection
2. ABSF Pattern Reduction
3. ABSF Offset Assignment
ABSF Offsetting – A Motivating Example
ABSF Offsetting – A Motivating Example

(a) No Offsetting

(b) ABSF Offsetting (Round Robin)
The question now is whether this improvement in the aggressor HeNBs throughput has an impact on the throughput of the macro-cell.

The delightfully 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 or do not even care how the offsetting is operated in HeNB’s.
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The Optimal ABSF Pattern Selection
A Nash Bargaining Approach
Nash 1953: “One states as axioms several properties that would seem natural for the solution to have and then one discovers that axioms actually determine the solution uniquely.”
Nash Bargaining - Axioms

- **PAR**
  - The solution is Parito Optimal

- **SYM**
  - The solution is Symmetric

- **TRA**
  - The solution is Invariant under Linear Transforms

- **IIA**
  - The solution is Independent of Irrelevant Alternatives
Nash Bargaining – The Solution

2 Players Solution

\[ NBS(S, d) = \max_{v_1, v_2} (v_1 - d_1)(v_2 - d_2) \]
\[ s.t \ (v_1, v_2) \in S \]

N Players Solution

\[ NBS(S, d) = \max_{v_1, v_2, \ldots, v_N} \prod_{i=1}^{N} (v_i - d_i) \]
\[ s.t \ (v_1, v_2, \ldots, v_N) \in S \]
Nash Bargaining – Proportional Fairness

\[ NBS(S, d) = \max_{v_1,v_2,\ldots,v_N} \prod_{i=1}^{N} (v_i - d_i) \]

Consider the special case when:

\[ d_i = 0 \quad \forall \ i \]

It’s proven that:

\[ NBS = \max_{v_1,v_2,\ldots,v_N} \prod_{i=1}^{N} v_i \quad \equiv \quad PFE = \max_{v_1,v_2,\ldots,v_N} \sum_{i=1}^{N} \log v_i \]
Pattern Selection Problem Formulation

• $\phi(S, d) = \max_{U \in S, U \geq d} U_{MeNB} = \max_{U \in S, U \geq d} (U_n - d_n). (U_v - d_v)$

$U_n = \prod_{i=1}^{N_n} (1 - \alpha) \cdot \frac{G(N_n)}{N_n} \cdot r_i \quad U_v = \prod_{j=1}^{N_v} \alpha \cdot \frac{G(N_v)}{N_v} \cdot r_j$

• $\phi(S, d) = \max_{U \in S} (\log U_n + \log U_v)$

$$\max_{U \in S} \left( N_n \times \log(1 - \alpha) + \sum_{i=1}^{N_n} \log \left( \frac{G(N_n)}{N_n} \cdot r_i \right) + N_v \right.$$  

$$\times \log \alpha + \sum_{j=1}^{N_v} \log \left( \frac{G(N_v)}{N_v} \cdot r_j \right) \right)$$
Modeling the problem as a Nash bargaining problem, we can find that the value of $\alpha$ that maximizes the aggregate macro-cell utility is:

$$\alpha = \frac{N_v}{N_n + N_v}$$

The ABSF pattern is selected via

$$I_{FDD} = \max(\min([\alpha.8], 3), 1)$$

$$I_{TDD} = \max(\min([\alpha.10], 2), 1)$$
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The Reduced ABSF Patterns and Offset Selection
Reduced ABSF Patterns

(a) No Offsetting

(b) ABSF Offsetting (Round Robin)
Pattern Reduction Problem Formulation

\[
\max_{U \in S} \sum_{h=1}^{H} \left( N_h \times \log(\beta_h) + \sum_{k=1}^{N_h} \log \left( \frac{G(N_h)}{N_h} \cdot r_k \right) \right)
\]

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

\[
\frac{\partial (\cdot)}{\partial \beta_i} = 0
\]

\[
\frac{N_i}{\beta_i} - \frac{N_h}{1 - \beta_1 - \beta_2 - \ldots - \beta_{h-1}} = 0 \quad \forall i
\]
Modeling the problem as a second stage of Nash bargaining, we can find that the value of $\beta_1, \beta_2, \ldots, \beta_h$ that maximizes the aggregate victim MUEs utility $U_v$ is:

$$\beta_i = \frac{N_i}{N_v}$$

The ABSF pattern is selected via

$$I_i = \max([\beta_i \cdot I_{FDD}], 1) \quad \forall i$$

$$I_i = \max([\beta_i \cdot I_{TDD}], 1) \quad \forall i$$
Reduced ABSF Patterns and Offsets

(c) Balanced ABSF Offsetting
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Performance Evaluation
### System Scenario

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td>HetNet in LTE-Advanced, deployment centered at 2000 MHz, with a carrier bandwidth = 5 MHz</td>
</tr>
<tr>
<td>Macro-cell</td>
<td>Cell with a radius of 500 m, and ~0.65 km² cell area, the eNB is centered in the cell area with omni 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 fully loaded, and therefore utilize all subcarriers.</td>
</tr>
<tr>
<td>Frequency Reuse</td>
<td>3</td>
</tr>
<tr>
<td>Duplex Technique</td>
<td>FDD</td>
</tr>
<tr>
<td>Scheduling Scheme</td>
<td>Modified Proportional Fair</td>
</tr>
<tr>
<td>Macro-cell Subscribers</td>
<td>12 MUEs uniformly distributed in the cell area with an 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 Subscribers</td>
<td>1 stationary HUE for each femto-cell, with an application of a rate 17.6 Mbps.</td>
</tr>
</tbody>
</table>
Throughput of the Macro-cell

![Graph showing the relationship between input load and aggregate throughput for different ABSF variations.](image-url)
Aggregate Throughput of the VMUEs

![Graph showing aggregate throughput of VMUEs with different ABSF configurations against input load of the macrocell.]
Aggregate Throughput of the Femto-Cells

- Non-ABSF
- ABSF 1/8
- ABSF 2/8
- ABSF 3/8
- ABSF 3/8 with offsetting

Aggregate throughput of the ABSF-mode triggered HeNBs (Mbps)

Input load of the macrocell (Mbps)

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Fairness Index of the Macro-cell UEs

![Graph showing the Fairness Index of the Macro-cell UEs with different input loads and ABSF settings.](image)
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Conclusion

- A novel algorithm called ABSF offsetting is proposed.
- 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.
Future Trends

- Formulation of Silence-Whisper scheme as a mix between ABSF and power control schemes.

- Applying the proposed schemes in a manner that is fully SON (Self Organizing Network) compliant.
Thanks

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