Issues in Femtocell Deployment in Broadband OFDMA Networks: 3GPP–LTE a case study

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Abstract

• Fourth Generation and beyond broadband wireless mobile networks, specifically 3rd Generation Partnership Project (3GPP)-Long Term Evolution (LTE) and beyond are considering issues related to the deployment of femtocells.

• Femtocells have the potential to improve Area Spectral Efficiency (ASE) several folds.

• However, interference is added to the system due to large number of uncontrolled, user-deployed femtocells.

• Hence improvement of overall system throughput becomes limited.

• In this paper, downlink coexistence between macro/micro cells and co-channel femtocells in Orthogonal Frequency Division Multiple Access (OFDMA)—Frequency Division Duplex (FDD) system based single frequency network is investigated.
Abstract

• The impact of density, load and transmit power variation of the femtocells on the performance of macro/micro cell and femtocell users
• as well as the effect of macro/micro cell load on femtocell performance is presented.
• Guidelines for femtocell deployment are derived with the objectives
  1. Maximizing Sum–Cell–Throughput
  2. Maximizing Number of Active Femtocells.
• Methods of centralized control as well mixed centralized and distributed control of femtocell radio parameters to meet the above objectives are presented.
• The analysis is done with International Telecommunication Union (ITU) specified channel models using system level simulator.
How it fits into big picture?

- **Advantages for Operator in Deployment of Femtocells (HeNB)**
  - Area Spectral Efficiency & Coverage Improvement
  - Traffic Offload to HeNB
    - Beat Wifi Competition
    - Same hardware & AI

- **Challenges**
  - Interference
    - Femtocell → Macrocell
    - Macrocell → Femtocell
    - Femtocell → Femtocell
  - Deployment Methods

- **Probable Approaches**
  - Self Configuration
    - Auto–Configuration of Radio Parameters
Problem Statement

- **Objective 1:**
  - Maximize: \[ \Sigma \text{Thpt}_{\text{macrocell}} + \Sigma \text{Thpt}_{\text{femtocell}} \](bps)

- **Objective 2:**
  - Maximize: No of Active Femtocell
  - Minimize: Interference ....

- **Controllable Parameters**
  - Femtocell parameter adjustment (*Degrees of Freedom*)
    - Femto-Power
    - Femto-Load
    - # Active Femtocell

- Macrocell Condition (Given / Changeable)
  - Macro-Load
  - # Macro-user
Femtocell Network Architecture

• **Distributed Control Methods**
  – *Only HeNB–H_{UE} co-ordination*
  – **No MeNB co-ordination**

• **Centralized Control Methods**
  – HeNB–MeNB co-ordination

• **Hybrid Control Methods**
  – Distributed + Centralized
Distributed Control Methods
Centralized Control Methods

- MeNB
- Enterprise HeNB
- BB Router
- BB Router
- BB Router

UEs attached to MeNB

- HeNB
- GW
- EPC
- MME
- S-GW
- MeNB Mgmt System
- HeNB Mgmt System

Internet

UEs attached to HeNB

HeNB

Centralized Control Methods
Centralized Control Methods

MeNB →

UEs attached to MeNB

Enterprise HeNB

BB Router

HeNB GW

EPC

MME

S-GW

MeNB Mgmt System

MeNB Mgmt System

HeNB Mgmt System

Internet

UEs attached to HeNB

HeNB

UEs attached to MeNB

BB Router
Analytical Framework

• Total System throughput

\[ C_{Tot} = \sum_{m=1}^{Num} 0.62 \log_2(1 + (\gamma_m / 1.8)) + \sum_{f=1}^{Nuf} 0.62 \log_2(1 + (\gamma_f / 1.8)) \]

• Average SINR in k\(^{th}\) subcarrier

\[ \gamma_k = \frac{P_{T,k}^{(0)} P_{g}^{(0)} G_{(\theta,\phi)}^{(0)} [ |h_{k,1}^{(0)}|^2 + |h_{k,2}^{(0)}|^2 ]^2}{P_{I,k}^{M} + P_{I,k}^{F} + [ |h_{k,1}^{(0)}|^2 + |h_{k,2}^{(0)}|^2 ] B_k \mathcal{F} N_0} \]
Analytical Framework

- Total interference received for neighboring macrocell

\[
P^{\text{M}}_{I,k} = \beta_m \times \sum_{m=1}^{N_{\text{eNB}}} P^{(m)}_{T,k} P^{(m)}_g G^{(m)}_{(\theta,\phi)} \left| (h^{(m)}_{k,1} h^{(0)*}_{k,1}) + (h^{(m)}_{k,2} h^{(0)*}_{k,2}) \right|^2
\]

- Total interference received for neighboring femtocell

\[
P^{\text{F}}_{I,k} = \beta_f \times \sum_{f=1}^{N_F} P^{(f)}_{T,k} P^{(f)}_g G^{(f)}_{(\theta,\phi)} \left| (h^{(f)}_{k,1} h^{(0)*}_{k,1}) + (h^{(f)}_{k,2} h^{(0)*}_{k,2}) \right|^2
\]
System Constraints

1. \( P_T^{(f)} \leq P_{T_{Max}}^{(f)} \)

2. \( P_T^{(m)} \leq P_{T_{Max}}^{(m)} \)

3. \( B \leq B_T \)

4. \( \{5\% \text{ point } C_{u_m} \} \geq C_{u_m}^{\min} \)

5. \( C_{u_f} \leq C_{u_f}^{th} \)
## Simulation Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cell Layout</strong></td>
<td>19 Cells, 3 Sectors, Wrap Around</td>
</tr>
<tr>
<td><strong>Scenario</strong></td>
<td>UMi</td>
</tr>
<tr>
<td><strong>ISD</strong></td>
<td>200m</td>
</tr>
<tr>
<td><strong>Bandwidth</strong></td>
<td>10MHz</td>
</tr>
<tr>
<td><strong>Channel Model</strong></td>
<td>as specified in ITU M-2135</td>
</tr>
<tr>
<td><strong>Carrier Frequency</strong></td>
<td>2.5GHz</td>
</tr>
<tr>
<td><strong>MeNB transmit power</strong></td>
<td>41dBm</td>
</tr>
<tr>
<td><strong>Maximum HeNB transmit power</strong></td>
<td>20dBm</td>
</tr>
<tr>
<td><strong>MeNB antenna height</strong></td>
<td>20m</td>
</tr>
<tr>
<td><strong>Number of Tx and Rx antennas</strong></td>
<td>$1 \times 2$</td>
</tr>
<tr>
<td><strong>MeNB antenna gain (boresight)</strong></td>
<td>17dB</td>
</tr>
<tr>
<td><strong>HeNB antenna gain</strong></td>
<td>0dB</td>
</tr>
<tr>
<td><strong>Thermal noise level</strong></td>
<td>$-174$dBm/Hz</td>
</tr>
<tr>
<td><strong>Receiver noise figure</strong></td>
<td>7dB</td>
</tr>
<tr>
<td><strong>UE speed</strong></td>
<td>3Kmph</td>
</tr>
<tr>
<td><strong>Minimum separation</strong></td>
<td>MeNB – macro/microUE : 20m. MeNB and HeNB : 20m. HeNB – femto UE : 1m. Inter HeNBs : 20m</td>
</tr>
<tr>
<td><strong>Shadow fading (\sigma) (dB)</strong></td>
<td>4 for outdoor users 7 for indoor users</td>
</tr>
<tr>
<td><strong>Shadowing correlation between sectors</strong></td>
<td>0.5</td>
</tr>
</tbody>
</table>
Results

Maximize: $\sum \text{System Capacity}$
Total System Capacity Evaluation

Maximum Achievable Mean System Throughput for various Macrocell conditions

- Maximum 613 Mbps system throughput achievable
- Offload Traffic

Maximum Achievable Mean System Throughput for various Macrocell conditions
Results

Maximize: No of active femtocell
Evaluation of allowable no of femtocell

Maximum Allowable Femtocells for various Macrocell conditions
Comparison of the two objectives

Macro-load = 25% and Number of Macro-user = 40

<table>
<thead>
<tr>
<th>Number of Active Femtocell</th>
<th>Objective 1: Maximizing total mean system throughput</th>
<th>Objective 2: Maximizing number of active femtocell</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>Total mean system throughput (Mbps)</td>
<td>211.27</td>
<td>184.22</td>
</tr>
</tbody>
</table>

150% increase in objective 2
12.8% decrease in objective 1
• With Hybrid control, individual Femto Load is adjusted (10%) if the corresponding femtocell mean throughput is $\geq 5\text{Mbps}$.

• For macro-load = 100% & macro-user = 85, there is 19% improvement in the 5% macrocell throughput with Hybrid control.
Macrocell user throughput (w and w/o Rate Control)

CDF of Macrocell user throughput

- Blue line: w/o Rate Control
- Pink line: with Rate Control

Scenario - UMi
- No of UEs - 100
- No of HeNB - 20
- MacroLoad - 100
- Initial FemtoLoad - 20

Macrocell-user Throughput (Kbps)
Key Achievements

• Guidelines for femtocell deployment with the objectives:
  – Maximizing total mean system throughput
  – Maximizing number of active femtocells

• Femtocell radio parameters adjustment through:
  – Methods of distributed control
  – Methods of centralized control
  – Methods of hybrid control
Conclusion

- Investigation of co-channel deployment of femtocell, in UMi scenario as per ITU channel model is presented in this work.

- Following two objective functions are studied
  - Maximization of sum–cell–throughput
  - Maximization of Active number of Femtocells.

- Clear guidelines are presented to attain these objectives for combinations of macro/micro cell users and macro/micro cell load by choosing appropriate
  - Femtocell Transmit Power
  - Femto Load
  - Number of Active Femtocells.
Conclusion

• It is found that offloading macro/micro cell traffic to femtocells helps in increasing sum–cell–throughput significantly.

• It is seen that up to 44 times increase in area spectral efficiency can be achieved by using co-channel femtocells in a UMi Scenario following the methods described in this work.

• A hybrid control strategy is also investigated which increases the 5% macro/micro user throughput by 19%.

• 2dBm to 5dBm of femto transmit power is sufficient to attain both the objective functions mentioned above.
Potential impact of the results

- Feasibility of deployment of femtocell in 4G network

- Femto Deployment Analysis Framework
  - Maximize: Total system throughput
  - Maximize: No of active femtocell

- Femtocell Deployment Guidelines
  - Transmit Power limit of Femtocell: 2dBm to 5dBm
  - Need for Coordination between Macro/Micro and Femto Cell layers
  - Load Adaptation in Macro & Femto Cell

For Deploying Agency

Operators
Industry Alignment of the work

Use of System Model specified by ITU \textit{[ITU M-2135], 3GPP LTE-A}

- Cellular layout
- Propagation environment
- Transmission Technology

INDUSTRY (Operators and Equipment Manufacturers)

- Guidelines for deployment of femtocells 3GPP – LTE Release 8/10 networks
  - \textit{Network capacity maximization}
  - \textit{Network optimization}
- Enhancement of the standards are per requirement of operators

Regulation through proper representation

- Country-wise Policy Making