Power control for interference management in LTE femto cell
An overview

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Presentation Outline

- Introduction to femto cell
- Interference problems in LTE femto cell
- Power control for interference management
  - downlink power controls
  - uplink power controls
  - advanced power controls
- Preliminary simulation results
- Concluding remarks
Why Femto at home?

- How many mobile phone calls are made at Home?

**Mobile Phone Usage in USA 2007**

<table>
<thead>
<tr>
<th>Location</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>At Home</td>
<td>39%</td>
</tr>
<tr>
<td>In Transport</td>
<td>32%</td>
</tr>
<tr>
<td>At Work</td>
<td>14%</td>
</tr>
<tr>
<td>Traveling</td>
<td>4%</td>
</tr>
<tr>
<td>Others</td>
<td>11%</td>
</tr>
</tbody>
</table>

**“Femto Cell Market to Reach $630 Million in 2010”**

Femto cell is one promising solutions for mobile coverage at home:

- Reliable communication
- Easy install
- Low price and OPEX
- Seamless handover
- Network integration

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1 – “The Case for Home Base Stations” tech. white paper by Femtoforum, Apr. 11, 2007
2 – “Mobile Phone Use in the Home is Growing” by David H. Deans, Sep. 29, 2008
3 – “Mobile market research report” by Infonetics Research, 2007

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Femtocell for LTE

"Macro" "Pico" "Femto"

Mobile Core Network

Gateway

Internet

eNB- evolved Node B; UE- User Equipment; HeNB- Home evolved Node B;

Macrocell

Picocell

Relay

UE

Backhaul

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Femto cell and spectrum efficiency

- We are running out of spectrum!

Since 1957, the wireless capacity has an approximately million fold increase, 25x improvement from wider spectrum, 5x improvement from dividing spectrum into smaller slices, 5x improvement by designing better modulation schemes, and a whopping 1600x gain through reduced cell sizes and transmit distance.\(^2\)

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What challenges Femtocell will bring?

- Technical challenges
  - Interference problems
  - Low cost implementation
  - Network and integration
  - Seamless handover

- Non-technical challenges
  - Low operating expenditure
  - Security problems
  - Lawful issues
  - Health care problems
Interference problems in LTE Femtocell

- Femtocell number per macro cell is indefinite
- Femtocell location can be without planning
- Frequency reuse strategy for LTE is already aggressive
- LTE air interfaces: OFDMA in downlink and FC-FDMA in uplink
- Restrictions on the functionalities of Home eNB
- Imperfect synchronization for Femtocells
- Priority issues
- Close/Open Connectivity issues

- Efforts from both academy and industries: esp. 3gpp ran4, ff wg2
OFDMA interference pattern in Downlink

- No intra-cell interference – orthogonal resource blocks
- Inter-cell Interference with perfect synchronization
- Inter-cell Interference with timing offset

\[ I(\Delta t, l) = \begin{cases} 
\delta(l) & 0 < \Delta t < t_{cp} \\
\sin(\pi l(t_{cp} - \Delta t)/T)^2/\pi l & t_{cp} < \Delta t < T + t_{cp} \\
0 & T + t_{cp} < \Delta t < T + 2t_{cp} 
\end{cases} \]

if \( \Delta t \) is uniformly distributed

\[ \bar{I}(l) = \begin{cases} 
2T + 3t_{cp} & l = 0 \\
6(T + t_{cp}) & l \neq 0 \\
T & l \neq 0 \\
1/2(T + t_{cp}) (\pi l)^2 & l \neq 0 
\end{cases} \]

**How serious are they?**

- Evaluate the influence of different types of interferences
  - mainly on Link budget study
  - Computer simulations
  - Field measurements

<table>
<thead>
<tr>
<th>Interference Types</th>
<th>Influence Level</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femto-to-Femto Interference in Femto uplink</td>
<td>Moderate</td>
<td>Rare to occur Tx power limit for Femto UE</td>
</tr>
<tr>
<td>Femto-to-Femto Interference in Femto downlink</td>
<td>Moderate</td>
<td>Adaptive power control Prevent dead zones</td>
</tr>
<tr>
<td>Macro-to-Femto Interference in Femto downlink</td>
<td>Low</td>
<td>Num. of affected users small</td>
</tr>
<tr>
<td>Femto-to-Macro Interference in Macro uplink</td>
<td>Moderate, potentially high</td>
<td>Limit Femto UE power</td>
</tr>
<tr>
<td>Macro-to-Femto Interference in Femto uplink</td>
<td>Low</td>
<td>Near-far effect</td>
</tr>
<tr>
<td>Femto-to-Macro Interference in Macro downlink</td>
<td>High</td>
<td>Handover, adaptive Femto BS power control</td>
</tr>
</tbody>
</table>

1 – “Interference Management in OFDMA Femtocells”, Femtoforum WG2 white paper, 2009
Power control algorithms

- PC algorithms existing in LTE macro cell
  - Downlink
    - basically constant
  - Uplink
    - Open loop – Fractional power control
    - Closed loop – link SINR measurement and control signaling via DL

- PC algorithms for LTE femto cell to develop
  - Downlink
    - non-constant transmit power
  - Uplink
    - Open loop – modified Fractional power control
    - Closed loop – may approach optimal power allocation

- Advanced PC algorithms
  - Joint PC with sub-band allocation etc. – additional degrees of freedom
  - Cooperative PC
Algorithms for Downlink femto cell PC

- to mitigate the Femto-to-Macro interference in Downlink

1. Based on distance to closet Macro eNB
   - Femto eNB’s location is known
   - far distance = reduce HeNB power

2. Based on pathloss to closet Macro eNB
   - measure signal strength of Macro DL

3. On detection of victim UEs
   - only protect when needed
   - if detected, strict HeNB power control
   - if not detected, soft power control

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Downlink PC with Connectivity issues

- ill “cell breathing” raises interference
Further on “cell breathing”

- Femtocell expands to unburden “Hot Spot” load
- Femtocell shrinks in “Cold Spot”
Algorithms for Uplink femto cell PC – Open Loop

- Conventional Fractional power control

\[ P_t = P_{\text{max}} \times \min \left\{ 1, \max \left[ R_{\text{min}}, \left( \frac{P_L}{P_{L_{x-ile}}} \right)^\gamma \right] \right\} \]

- \( P_{\text{max}} \) is the power cap (cell specific)
- \( \gamma \) is the fractional factor

- Modifications on FPC
  - Macro eNBs adjust \( P_{\text{max}} \) of the Femtocells in their vicinity
    - higher UL interference -> reduce \( P_{\text{max}} \)
  - Macro eNBs adjust \( \gamma \) or \( P_{L_{x-ile}} \) of the Femtocells in their vicinity
    - \( \gamma \) is a balancing factor between throughput and system coexistence

- Parameter sets proposed by 3GPP RAN4

<table>
<thead>
<tr>
<th>Parameter set</th>
<th>Gamma (( \gamma ))</th>
<th>PLx-ile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>10 MHz bandwidth</td>
</tr>
<tr>
<td>Set 1</td>
<td>1</td>
<td>112</td>
</tr>
<tr>
<td>Set 2</td>
<td>0.8</td>
<td>129</td>
</tr>
</tbody>
</table>

1 – 3GPP R4-091796, May 2009
Algorithms for Uplink femto cell PC – Closed Loop

- optimal power controls
  - interference limited network, e.g. CDMA
  - assign target SIR
  - measure current UL SIR
  - feedback to UE via DL

Minimize \[ \sum_i p_i \]
subject to \( SIR_i(p) \geq \gamma_i \), for \( \forall i \)
variables \( p \)

\[ p_i[t+1] = \frac{\gamma_i}{SIR_i[t]} p_i[t] \]
Fractional Frequency Reuse with PC

- Traffic demand on Femtocell is relatively low
- Optimal FFR allocation with joint power control
- Randomly FFR allocation
Joint PC and FFR

- FFR scheme 1 (baseline)
- FFR scheme 2

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Joint PC and FFR

- FFR scheme 3

- FFR scheme 4

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Preliminary results 500x Monte Carlo simulation

sum. TX Power vs. Num of Femtos

average Sum TX Power (dBm)

Num of Femto BSs

FFR3
FFR4
FFR1
FFR2

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Outage Probability vs. Num. of Femtos

- FFR3
- FFR4
- FFR1
- FFR2

Power Outage Probability (%)

Num. of Femto BSs

0 50 100 150 200 250 300 350 400 450 500

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Besides FFR and power control

- Smart scheduling
  - Femtocell and Macrocell cooperative scheduling
  - Interference sensing and opportunistic scheduling
  - Time, frequency, antenna degrees of freedom

- Operators indoor band sharing
  - Win-win to all

- TDD at UL FDD
  - Uplink channel in FDD is not always crowded
  - TDD works well for indoor
Concluding remarks

- Femto cell is a promising technology
- Interference is one of the major problems for femto cell
- Power control can mitigate some interference but not all
- Advanced interference mitigations have to be developed
- Lots of works need to be done in experiment and measurement
Thank you for your attention