Mobility Management for Femtocells in LTE-Advanced: Key Aspects and Survey of Handover Decision Algorithms

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Table of Contents

• Small Cells
  – Key features
  – Femtocells
• LTE-Advanced
• Part I: Mobility Management for femtocells in LTE-Advanced (LTE-A)
  – Network architecture and support of femtocells
  – Cell Identification
  – Access Control
  – Cell Search
  – Cell Selection/Reselection
  – Handover Decision
  – Handover Execution
Table of Contents

- Part II: Handover decision for femtocells in LTE-Advanced (LTE-A)
  - Handover Decision Criteria and Context
  - Classification of Handover Decision Algorithms
  - Survey of Handover Decision Algorithms
  - Performance Evaluation and Modeling Issues
  - Comparative Summary
  - Future Research Directions

Part II: Handover Decision for femtocells in LTE-Advanced

• Overview of Part II
  – Handover Decision Criteria and Context
  – Classification of Handover Decision Algorithms
  – Survey of Handover Decision Algorithms
  – Performance Evaluation and Modeling Issues
  – Comparative Summary
  – Future Research Directions
Part II: Handover Decision for femtocells in LTE-Advanced

• Classification of Handover Decision Algorithms
Part II: Handover Decision for femtocells in LTE-Advanced

- Survey of Handover Decision Algorithms
  - Three representative HO algorithms per class
  - Overview key features and give algorithmic flowchart
  - Summarize the main advantages / disadvantages
  - Adapt the presentation to the LTE-A system and use a common notation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Notation</th>
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<tbody>
<tr>
<td>Serving cell</td>
<td>$s$</td>
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<tr>
<td>Candidate cell</td>
<td>$c$</td>
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<tr>
<td>Set of candidate cells</td>
<td>$L$</td>
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<tr>
<td>Reference Signal Received Power (RSRP) of a tagged cell $c$</td>
<td>$\text{RSRP}(c)$</td>
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<tr>
<td>Minimum RSRP threshold for sustaining service continuity</td>
<td>$\text{RSRP}_{th}$</td>
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<tr>
<td>Reference Signal Received Quality (RSRQ) of a tagged cell $c$</td>
<td>$\text{RSRQ}(c)$</td>
</tr>
<tr>
<td>Minimum RSRQ threshold for sustaining service continuity</td>
<td>$\text{RSRQ}_{th}$</td>
</tr>
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<td>Received Interference Power in a tagged cell $c$</td>
<td>$I(c)$</td>
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<tr>
<td>Downlink Reference Signal Transmit Power of a tagged cell $c$</td>
<td>$P_{RS}(c)$</td>
</tr>
<tr>
<td>Signal to Interference plus Noise Ratio (SINR) for cell $s$</td>
<td>$\text{SINR}(s)$</td>
</tr>
<tr>
<td>Handover Hysteresis Margin (HHM) for a tagged cell $c$</td>
<td>$\text{HHM}(c)$</td>
</tr>
<tr>
<td>Time to Trigger</td>
<td>$\text{TIT}$</td>
</tr>
<tr>
<td>UE speed</td>
<td>$V$</td>
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<tr>
<td>UE speed threshold</td>
<td>$V_{th}$</td>
</tr>
</tbody>
</table>
Part II: Handover Decision for femtocells in LTE-Advanced

• Performance Evaluation and Modeling Issues
  – The performance of existing algorithms is evaluated either based on simulations [45]-[47], [50], [52]-[53], [55]-[60] or on analytical modeling [41]-[43] [48]
  – Recent trends for performance evaluation and modeling
    • System-level simulations using the Small Cell Forum evaluation methodology [110]
    • Performance Analysis using Stochastic Geometry [111]
Part II: Handover Decision for femtocells in LTE-Advanced

- Performance Evaluation and Modeling Issues
  - Small Cell Forum evaluation methodology for system-level simulation model
    - Main cluster area consists of 7/19 eNBs
      - Each cell has 3 sectors
    - 7 clusters using the wrap-around technique
    - **Femtoblocks**: set of blocks of apartments
      - Models for suburban, urban and dense urban environment
    - **Femtocell deployment ratio** $r_{fc}$
      - Percentage of apartments with a femtocell installed
    - **Femtocell activation ratio** $a$
      - Percentage of time where the femtocell is on
  - An additional parameter can be used
    - **Femtoblock deployment density** $d_{FB}$
      - Percentage of the main cluster area covered with femtoblocks
Part II: Handover Decision for femtocells in LTE-Advanced

• Performance Evaluation and Modeling Issues
  – Small Cell Forum evaluation methodology for system-level simulation model
    • Macrocell users uniformly dropped in the sectors
    • Femtocell stations uniformly dropped inside the apartments
    • Femtocell users uniformly dropped inside the apartments (a minimum separation is provisioned)
    • CSG or hybrid cells
    • Provision for various network and femtoblock layouts
    • Path loss models adapted depending on the femtoblock layout
      – Depend on the serving cell type and the user location
    • Monte-Carlo sampling
Part II: Handover Decision for femtocells in LTE-Advanced

• Performance Evaluation and Modeling Issues
  – Small Cell Forum evaluation methodology for system-level simulation model

• Network layout and femtoblock models
Part II: Handover Decision for femtocells in LTE-Advanced
Part II: Handover Decision for femtocells in LTE-Advanced

- Performance Evaluation and Modeling Issues
  - Small Cell Forum evaluation methodology for system-level simulation model: Mobility and Path Loss models

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>User speed at time t</td>
<td>( v_t = N(\bar{v}, s_u) ) (m/s)</td>
</tr>
<tr>
<td>User direction at time t</td>
<td>( \varphi_t = N\left(\varphi_{t-1}, 2\pi - \varphi_{t-1}\tan(\frac{\varphi_t}{2})\Delta t\right) ), where ( \bar{v} ) is the mean user speed, ( s_u ) the user speed standard deviation, ( \Delta t ) the time period between two consecutive updates of the model and ( N(a, b) ) indicates a Gaussian distribution of mean ( a ) and standard deviation ( b )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Mobility model [12]</td>
<td></td>
</tr>
<tr>
<td>UE to Macrocell</td>
<td>( PL(dB) = 15.3 + 37.6 \log_{10}d )</td>
</tr>
<tr>
<td>UE outdoors</td>
<td>( PL(dB) = 15.3 + 37.6 \log_{10}d + L_{ow} )</td>
</tr>
<tr>
<td>UE indoors</td>
<td></td>
</tr>
<tr>
<td>UE to Femtocell</td>
<td>( PL(dB) = 38.46 + 20 \log_{10}d + 0.7d_{\text{indoor}} + w \cdot L_{iw} )</td>
</tr>
<tr>
<td>UE in the same apartment stripe</td>
<td></td>
</tr>
<tr>
<td>UE outside the apartment stripe</td>
<td>( PL(dB) = \max(15.3 + 37.6 \log_{10}d, 38.46 + 20 \log_{10}d + 0.7d_{\text{indoor}} + w \cdot L_{iw} + L_{ow} )</td>
</tr>
<tr>
<td>UE inside a different apartment stripe</td>
<td>( PL(dB) = \max(15.3 + 37.6 \log_{10}d, 38.46 + 20 \log_{10}d + 0.7d_{\text{indoor}} + w \cdot L_{iw} + 2 \cdot L_{ow} )</td>
</tr>
</tbody>
</table>
Part II: Handover Decision for femtocells in LTE-Advanced

- Performance Evaluation and Modeling Issues
  - Analytical modeling using Stochastic Geometry
    - Growing literature for modeling large-scale wireless networks using SG
    - Calculates spatial averages that capture the key dependencies of the network performance as a function of a relatively small number of system parameters
      - Interference, outage probability, transmission capacity
    - SG models basic network properties by averaging over all potential geometrical patterns
  - Main SG study object: Point Processes (PP)
    - *Simple or not*: multiplicity of a point is at most one
    - *Stationary or not*: the law of the PP invariant to translation
    - *Isotropic or not*: the law of the PP invariant to rotation
    - *Marked or not*: marks assign labels to the points of the PP, which are typically independent of the PP and i.i.d.
Part II: Handover Decision for femtocells in LTE-Advanced

• Performance Evaluation and Modeling Issues
  – Analytical modeling using Stochastic Geometry
  – Poisson PP (PPP) is the most commonly used PP
    • Offers the highest level of analytical tractability
    • Key properties
      – Superposition: the superposition of two or more independent PPP is again a PPP
      – Independent thinning: the PP obtained by randomly and independently removing a point from the initial PPP is still a PPP
      – Displacement theorem: the PP obtained by displacing a point independently of everything else, according to some Markov kernel that defines the distribution of the displaced position of the point, yields another PPP
Part II: Handover Decision for femtocells in LTE-Advanced

- Network layout
  - Maximum SINR connectivity
Part II: Handover Decision for femtocells in LTE-Advanced
Part II: Handover Decision for femtocells in LTE-Advanced

• Performance Evaluation and Modeling Issues
  – Analytical modeling using Stochastic Geometry
  – Existing results using SG
    • Interference, outage probability, transmission capacity, and spectral efficiency of distributed wireless networks [112]-[114]
    • SG has been used to evaluate the performance of multi-tier cellular networks [65], [115]-[117]
  – Beyond State of the Art for HO decision and SG
    • Capture the impact of user mobility [118]
      – Most of the existing works assume static network topologies
    • Allow for varying cell and UE transmit power [116]
      – Most of the existing works assume fixed transmit power
    • Performance analysis with regards to the HO probability
Part II: Handover Decision for femtocells in LTE-Advanced

• Comparative Summary
  – Existing HO decision algorithms
    • Divergent system models and assumptions, simulation setups, and performance measures
      – Difficult to readily compare them
  – Comparison based on
    • The HO decision parameters
    • The HO decision scenario under consideration
    • The performance evaluation methodology
    • Their key features
## Part II: Handover Decision for femtocells in LTE-Advanced

### RSS related
- RSS: Y v v v v v v v v v v
- Minimum required RSS for service continuation: Y v v v v v v v v v v
- Path loss: Y
- RS transmit power: Y
- Window function on the RSS: Y v

### Handover Hysteresis Margin related
- HHM: Y v v v v v v v v v v

### Interference related
- RSQ: Y v v v v v v v v v v
- Received interference power at the cell sites: Y
- Interference constraints on the target cell(s): Y

### Speed related
- UE speed: Y v v v v v v v v v v
- UE residence time in the cell: Y
- UE mobility pattern: Y

### Bandwidth related
- Available bandwidth / Cell load: Y v v v v v v v v v v
- Cell capacity: Y
- Number of camped UEs on the target cell: Y
- Number of UE connections per traffic-type: Y
- Cell type: Y

### Traffic related
- Traffic-type: Y v v v v v v v v v v
- Mean SINR target of the UE: Y
- Bit Error Rate (BER): Y
- Current SINR at the serving cell: Y

### Energy-efficiency related
- UE power class: Y
- UE battery power: Y
- Mean UE transmit power: Y

### Other
- UE membership status: Y
- UE priorities: Y
Part II: Handover Decision for femtocells in LTE-Advanced

• Comparative Summary
  – HO decision parameters
    • RSS is a common basis for HO decision making
    • RSQ is typically used as an SINR estimate
    • UE speed broadly used to anticipate the negative impact of user mobility
    • Available bandwidth utilized to lower the HO failure probability due to the lack of resources
    • Traffic-type is used to avoid frequent service interruption for delay-sensitive services
Part II: Handover Decision for femtocells in LTE-Advanced

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<tr>
<th>Points of Comparison</th>
<th>Algorithms</th>
<th>RSS-based</th>
<th>Speed-based</th>
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<th>E. E.</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Moon et. al. [42]</td>
<td>Xie et. al. [43]</td>
<td>Perez et. al. [44], [45]</td>
<td>Jeong et. al. [46]</td>
<td>Ulmer et. al. [47]</td>
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<td>Wong et. al. [48]</td>
<td>Zhang et. al. [49]</td>
<td>Wu et. al. [50]</td>
<td>Zhang et. al. [51]</td>
<td>Xu et. al. [52]</td>
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<td>Shaohai et. al. [53]</td>
<td>Lee et. al. [54]</td>
<td>Rego et. al. [55]</td>
<td>Xie et. al. [56]</td>
<td>Zhang et. al. [57]</td>
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<td>Zhi et. al. [58]</td>
<td>Yang et. al. [59]</td>
<td>Feng et. al. [60]</td>
<td>Becvar et. al. [61]</td>
<td>Xenakis et. al. [62]</td>
</tr>
</tbody>
</table>

**HO DECISION SCENARIO**

| Single-macrocell single-femtocell for inbound HO to femtocell | v | v | v | v | v | v | v |
| Single-macrocell single-femtocell | v | v | v | |
| Single-macrocell multiple-femtocell | v | v | |
| Multiple-macrocell multiple-femtocell | v | v | |

**PERFORMANCE EVALUATION RESULTS**

<table>
<thead>
<tr>
<th>Analytical (A) / Simulation (S) results</th>
<th>A</th>
<th>A</th>
<th>S</th>
<th>S</th>
<th>A</th>
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<tr>
<td>HO probability</td>
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<td>HO failure probability</td>
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<td>Assignment probability to femtocell</td>
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<td>Assignment probability to macrocell</td>
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<td>Number of HOs</td>
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<td>Number of unnecessary HOs</td>
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<td>Unnecessary HO probability</td>
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<tr>
<td>Impact of the HHM</td>
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<td>Throughput</td>
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<td>Signaling overhead</td>
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<td>Transmit power</td>
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<td>Received interference power</td>
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<td>Energy consumption per bit</td>
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<tr>
<td>Power consumption</td>
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<tr>
<td>Uses the evaluation methodology in [110]</td>
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<tr>
<td>Includes a comparison with other algorithms</td>
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<tr>
<td>Accounts for uneven RS transmit powers</td>
<td>Moon et al. [41], [42], Xu et al. [43], Perez et al. [44], [45], Jeong et al. [46]</td>
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<tr>
<td>Accounts for the impact of interference by using the RSRQ/SINR status</td>
<td>Perez et al. [44], [45], Jeong et al. [46], Zhang et al. [48], Wu et al. [49], Zhang et al. [50], Xu et al. [52], Lee et al. [53], Xie et al. [54], Xenakis et al. [55], Yang et al. [56], Chen et al. [57], Kim et al. [58], Becvar et al. [59], Xie et al. [60]</td>
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<td>Accounts for the impact of interference by using the RIP at the cell sites</td>
<td>Perez et al. [44], [45], Jeong et al. [46], Zhang et al. [48], Wu et al. [49], Zhang et al. [50], Xu et al. [52], Lee et al. [53], Xie et al. [54], Xenakis et al. [55], Yang et al. [56], Chen et al. [57], Kim et al. [58], Becvar et al. [59], Xie et al. [60]</td>
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<tr>
<td>Accounts for potential IF limitations at the cells</td>
<td>Perez et al. [44], [45], Jeong et al. [46], Zhang et al. [48], Wu et al. [49], Zhang et al. [50], Xu et al. [52], Lee et al. [53], Xie et al. [54], Xenakis et al. [55], Yang et al. [56], Chen et al. [57], Kim et al. [58], Becvar et al. [59], Xie et al. [60]</td>
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<tr>
<td>Jointly performs interference mitigation and HO</td>
<td>Perez et al. [44], [45], Jeong et al. [46], Zhang et al. [48], Wu et al. [49], Zhang et al. [50], Xu et al. [52], Lee et al. [53], Xie et al. [54], Xenakis et al. [55], Yang et al. [56], Chen et al. [57], Kim et al. [58], Becvar et al. [59], Xie et al. [60]</td>
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<td>Performs preliminary admission control</td>
<td>Perez et al. [44], [45], Jeong et al. [46], Zhang et al. [48], Wu et al. [49], Zhang et al. [50], Xu et al. [52], Lee et al. [53], Xie et al. [54], Xenakis et al. [55], Yang et al. [56], Chen et al. [57], Kim et al. [58], Becvar et al. [59], Xie et al. [60]</td>
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<tr>
<td>Enables load balancing</td>
<td>Perez et al. [44], [45], Jeong et al. [46], Zhang et al. [48], Wu et al. [49], Zhang et al. [50], Xu et al. [52], Lee et al. [53], Xie et al. [54], Xenakis et al. [55], Yang et al. [56], Chen et al. [57], Kim et al. [58], Becvar et al. [59], Xie et al. [60]</td>
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</tr>
<tr>
<td>Uses a HHM to lower the HO probability and minimize the ping-pong effect</td>
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<td>Requires the assessment of the UE speed</td>
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<td>Uses mobility prediction for HO mitigation</td>
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<td>Accounts for the UE service requirements/characteristics</td>
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<td>Requires interventions to the standard network functionality or architecture</td>
<td>Perez et al. [44], [45], Jeong et al. [46], Zhang et al. [48], Wu et al. [49], Zhang et al. [50], Xu et al. [52], Lee et al. [53], Xie et al. [54], Xenakis et al. [55], Yang et al. [56], Chen et al. [57], Kim et al. [58], Becvar et al. [59], Xie et al. [60]</td>
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<td>The signaling procedure for supporting the algorithm is described, e.g., parameter acquisition</td>
<td>Perez et al. [44], [45], Jeong et al. [46], Zhang et al. [48], Wu et al. [49], Zhang et al. [50], Xu et al. [52], Lee et al. [53], Xie et al. [54], Xenakis et al. [55], Yang et al. [56], Chen et al. [57], Kim et al. [58], Becvar et al. [59], Xie et al. [60]</td>
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<td>Algorithm-related parameters are fully specified</td>
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Part II: Handover Decision for femtocells in LTE-Advanced

• Comparative Summary
  – RSS-based algorithms
    • Strong Aspects
      – Low-complexity and easier to validate through performance analysis
      – Require minimum network interventions unless more sophisticated capabilities are deployed
        » Interference mitigation [44]-[45] or mobility prediction [46]
    • Weak Aspects
      – They do not account for the impact of interference on the SINR, throughput and energy consumption performance
      – Interference-agnostic
Part II: Handover Decision for femtocells in LTE-Advanced

• Comparative Summary
  – Speed-based algorithms
    • Strong Aspects
      – Reduce the HO probability for medium to high speed users
      – Reduce the number of unnecessary HOs in the system
    • Weak Aspects
      – Arbitrary selection of the UE speed thresholds
      – Typically do not incorporate the monetary, signaling or energy consumption overhead for assessing the UE speed
      – The impact of the algorithms on the interference and throughput performance is not assessed
Part II: Handover Decision for femtocells in LTE-Advanced

• Comparative Summary
  – Cost-function based algorithms
    • Strong Aspects
      – Incorporate a wide set of parameters to reach a HO decision
      – Perform preliminary admission control or load balancing by incorporating bandwidth-related parameters
    • Weak Aspects
      – Do not provide a detailed methodology for calculating the optimal weights or adjustment factors of the cost-function
      – The performance of the algorithms is typically evaluated by fixing the weights and adjustment factors of the cost-function
Part II: Handover Decision for femtocells in LTE-Advanced

• Comparative Summary
  – Interference-aware algorithms
    • Strong Aspects
      – Improve the SINR performance in the system
      – Allow for interference handling at a macroscopic level
    • Weak Aspects
      – RSQ based algorithms: Need to incorporate a HHM to lower the HO probability and reduce the ping-pong effect
        » RSQ can be subject to fast variations
      – RIP based algorithms: Need to deploy more complicated signaling procedures
        » Commute the cell RIP of the target cells to the serving cell
Part II: Handover Decision for femtocells in LTE-Advanced

• Comparative Summary
  – Energy-efficient algorithms
    • Strong Aspects
      – Reduce the energy expenditure per bit
      – Improve the SINR performance in the system
      – Enhance the QoE of the users
    • Weak Aspects
      – Increase the signaling and processing overhead to keep track or estimate the energy-efficiency at the network nodes
Part II: Handover Decision for femtocells in LTE-Advanced

• Comparative Summary
  – Future Research Directions
    • Need for HO decision algorithms that apply to the multiple-macrocell multiple-femtocell scenario
      – The number of femtocells is expected to surpass that of macrocells by up to six times before 2016 [119]
      – Existing algorithms typically apply to the inbound mobility scenario to femtocell with single-macrocell single-femtocell
    • Attain backwards compatibility with the cellular standard
      – Specify the additional network functionality and the required network signaling procedures
    • Use of a HHM during the RSS / RSQ comparison
      – Anticipate with the fast variations of the wireless medium
      – Mitigate the ping-pong effect
      – Combined with speed-based criteria, the HHM reduces the HO probability for medium to high speed users
      – The HHM selection should be optimized
Part II: Handover Decision for femtocells in LTE-Advanced

• Comparative Summary
  – Future Research Directions
    • Integrate bandwidth-based HO decision criteria
      – Increase the spectrum availability for the UEs
      – Perform preliminary admission control and load-balancing
      – Reduce the HO failure probability due to lack of resources
    • Account for the ongoing connections’ characteristics
      – Prescribed mean SINR target [55] [60] or traffic-type of the user connections [43] [49] [52]
      – Enhance the QoE
Part II: Handover Decision for femtocells in LTE-Advanced

• Comparative Summary
  – Future Research Directions
    • Validate the performance of the proposed algorithms by using realistic system assumptions or simulation setups
      – Existing algorithms accompanied with performance analysis focus on simple network layouts
      – Only a few works conduct system-level simulations based on the evaluation methodology of the Small Cell Forum
      – Compare the performance of the algorithms against other competing ones
      – Focus on performance measures closely related to the femtocell operation
        » Interference, Energy Consumption, Throughput
Part II: Handover Decision for femtocells in LTE-Advanced

• Conclusions
  – The smooth integration of femtocells dictates architectural and procedural enhancements that go beyond the standard cellular operation
  – Open Issues for MM in the presence of femtocells
    • Cell Identification
      – Develop more sophisticated procedures to uniquely and swiftly identify the femtocell infrastructure
      – Propose distributed PCI selection algorithms for coping with the random yet dense femtocell deployment
    • Cell Search
      – Design UE-based autonomous cell search algorithms
        » Use of cognition, context-awareness and cooperation
      – Develop femtocell-specific DRX and packet scheduling algorithms
        » Utilize the exciting new IMT-Advanced capabilities
Part II: Handover Decision for femtocells in LTE-Advanced

• Conclusions
  – Open Issues for MM in the presence of femtocells
    • Cell Selection/Reselection
      – Design femtocell-specific selection / reselection strategies
        » Use of cognition, context-awareness and cooperation
      – Optimize the formation of tracking areas
    • HO Decision
      – Focus on the multiple-macrocell multiple-femtocell case
      – Specify the additional network functionality and the required network signaling procedures
      – Utilize a HHM during the RSS/RSQ comparison
        » Optimized selection is required
      – Be based on the recent trends for femtocell-specific performance evaluation
    • HO Execution
      – Develop novel signaling methods and protocols to smoothly integrate femtocell-specific processes
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References


References

References

References


References

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Thanks for your kind attention!

Questions?

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Component and System-Level Energy Saving for femtocells in Future Mobile Heterogeneous Networks

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Table of Contents

• Component and System Level Energy Saving for femtocells in Future Mobile Heterogeneous Networks
  – Understanding the EE of the mobile operator’s network
    • Introduction
    • Energy consumption composition
    • Radio Access Network Energy Saving
    • EE model for outdoor Radio Base Stations
    • Forecasts for cellular deployment
  – Component-level Energy Saving
    • Energy Consumption model for femtocells
    • Component-Level Energy Saving Opportunities
  – System-level Energy Saving
    • Time Domain approaches
    • Frequency Domain approaches
    • Spatial Domain approaches
    • Research Directions
References

• This presentation is based on the following references
  

Introduction

• Mobile industry faces a critical energy consumption challenge
  – More wireless infrastructure has to be deployed
    • Smart-phones will exceed 1.82 billion units by 2013
    • Network load increases 10-fold every five years
      – Energy consumption increase of 16-20%
  – Mobile communications contribute 15-20% of the entire ICT energy footprint
    • 0.3-0.4 % of global CO2 emissions
  – Need for energy-efficient wireless networking
Energy consumption composition of a mobile operator

- Radio base station (RBS): 57%
- Mobile telephone exchange (MTX): 20%
- Core network: 15%
- Data center: 6%
- Retail: 2%
Radio Access Network

• Radio Access Network: The key energy contributor for a mobile operator

• Motivation for focusing on ES for the RAN
  – Wireless standards traditionally focus on maximizing the user throughput
    • Performance trade-offs: Energy Efficiency (EE) vs Throughput
  – Mobile users urgently ask for enhanced EE
    • Enjoy better mobile services and improve their Quality of Experience (QoE)
  – Provides a big energy saving pool

• Key issues
  – How will the cellular RAN evolve?
  – How to model the EE of a RBS?
How will the cellular RAN evolve?

Forecasts for cellular deployment

• Femtocell Market Status
  – 10-fold increase in the number of deployed femtocells from 2012 to 2015
  – The number of deployed femtocells will surpass that of deployed macrocells by six times

• ES for femtocells is challenging
  – Femtocells are deployed and managed by the consumer
  – Unplanned deployment
  – Dense and overlapping deployment
  – Plug and play operation – self-x operation
How to model the EE of a RBS?

• ETSI EE model for outdoor RBS
  – RBS equipment
    • Serves one or more interfaces to the mobile device
    • Radio transceivers: Responsible for transmission and reception of radio signals, include RF Power Amplifiers (PA)
      – The PA amplifies the signal for transmission via antenna
      – In case of no traffic load, the RBS equipment could enter the idle mode (ES)
  – Support systems for the RBS
    • Power Supply (PS)
      – Connects to the AC power line or battery, and offers electrical energy to the equipment
    • Climate Control
      – Maintains the operating climate of the equipment within a defined range
    • Transmission Module (TXM)
      – Connects the RBS to the core network
    • Battery backup
      – Supplies energy to the RBS when the AC power line is down
ETS1 EE model for an outdoor RBS

- EE is defined as the ratio of the radiated to the feeding power
RAN Energy Saving Approaches

• Radio Access Network
  – Energy Saving approaches for femtocells
  • Component-level energy saving
    – Optimize the performance of the various (hardware) components of the femtocell
      » Digital Baseband Engine, Power Amplifier, Analog RF transmitter, matching network
  • System-level energy saving
    – Modify some of the fundamental network parameters to save energy
      » Cell bandwidth, number of carriers, number of antennas, Number/density of cellular stations in the network
Component-Level Energy Saving for femtocells

Simplified block diagram of a pico/femto-cell base-station

RBS power consumption breakdown for different cell-sizes
Component-Level Energy Saving Opportunities

- Base-stations are designed for serving high traffic load and achieve their maximum performance
- The daily data traffic profile for cellular systems in a dense urban environment shows high variations
  - The highest utilization is observed between 18.00 and 24.00
Daily (24h) data traffic profile for cellular systems (Dense urban)

Key idea: Adapt the operation of the various femtocell components with respect to the traffic load
Component-Level Energy Saving: Digital Baseband Engine (DBE)

- **DBE functionality**
  - Frequency-domain processing for modulation/demodulation or equalization, channel coding/decoding, pre-distortion, platform control and backbone network serial link

- **The energy consumption of the DBE is becoming more and more dominant**
  - Due to the shrinking cell size and the rapidly growing signal processing complexity

- **Enable energy scalability depending on the signal load**
  - Bandwidth, modulation, coding rate, number of antennas, duty-cycling in time or frequency
Component-Level Energy Saving:
Digital Baseband Engine
Component-Level Energy Saving: RF Transceiver

• The RF transceiver of traditional base-stations, targets to achieve the best SiNAD performance independent of the signal load
  – Signal-to-noise and distortion ratio (SiNAD) is a measure of the quality of a signal from a communications device

• Scale the transceiver to provide a ‘just good enough’ SiNAD performance depending on the current signal load (SDR technology)
Component-Level Energy Saving: RF Transceiver
Component-Level Energy Saving: Power Amplifier

• The PA is not the major energy consumption contributor in femtocells

• Adaptive Energy Efficient Power Amplifier
  – Adjust the PA Operating Point
    • The PA operating point can be optimized according to the required RF output power level (traffic load), while fulfilling the spectral mask and PAPR specifications
  – Enable fast switching on/off of the RF power transistor
    • Minimum consumption when no RF output power is required
Component-Level Energy Saving: Power Amplifier

- OP5: <20% load, OP4: 20%-40% load, OP3: 40%-60% load, OP2: 60%-80% load, OP1: 80%-100% load
System-Level Energy Saving
System-Level Energy Saving: Time domain

- Time domain solutions temporally shut down PAs in a RBS when there is no data traffic in the downlink
  - Tightly related to the frame structure of the cellular system
  - Three basic ways to temporally shut down PAs
    - Turning off a PA in signal-free symbols
    - Using a multicast broadcast single frequency network (MBSFN) subframe to reduce RSs
    - Use the extended cell discontinuous transmission (DTX) to further reduce the number of RSs
System-Level Energy Saving: 
Time domain
System-Level Energy Saving: Time domain

- **PA Off at Signal-Free Symbol**
  - Turn off PAs in time periods of a slot where downlink symbols are signal-free
  - Signal-free periods do not include DL RSs and control signals
  - Assuming it takes half of a symbol time to turn on a PA but the PA can be immediately turned off: The PA is only required to be on for at least 47% of the time in a frame
System-Level Energy Saving: Time domain

• Utilize the MBSFN frame structure
  – MBSFN is proposed to deliver services such as mobile TV using the LTE infrastructure
  – In an MBSFN frame, the symbols for RS in subframes 1–4 and 6–9 are reduced to 1
  – Use the MBSFN structure to further reduce the number of RSs
    • The PA operating time during a frame is then reduced to 28 percent
System-Level Energy Saving: Time domain

• Utilize the Extended Cell DTX mode (3GPP)
  – The extended cell DTX allows to further reduce RSs compared to the MBSFN approach
  – If there is no downlink traffic, in the extended cell DTX mode there is no need to have any transmission in subframes 1–4 and 6–9 of a frame
  – The PA operating time in a frame is further reduced to 7.1 percent
System-Level Energy Saving: Time domain

- **Advantages**
  - Significantly reduce the PA operation time when a cell is idle (apply better in rural areas)
  - Need for joint time-frequency domain scheduling to make them effective in urban areas as well, and only under low traffic conditions

- **Disadvantages**
  - Without enough RSs, some UEs may experience unpredictable problems synchronizing with an RBS or decoding control signals
  - Reducing RSs may also prevent UE from entering into terminal DTX mode and thus shorten its battery life
System-Level Energy Saving: Frequency domain

• Bandwidth Reduction
  – Existing cellular systems allow for scalable bandwidth utilization
  – Adapt the cell bandwidth depending on the downlink traffic load
    • Lower the overall transmit power and reduce the number of DL RSs
  – This approach is suitable only for low traffic
  – Marginal gains given that the PA is still active
System-Level Energy Saving: Frequency domain

• Carrier Aggregation
  – Shut down the associated PAs when the corresponding aggregated carriers are not scheduled for the downlink traffic
  – Applicable to an RBS that has aggregated carriers and separate PAs attached to each group of carriers
System-Level Energy Saving: Frequency domain

• Advantages
  – Frequency domain approaches are backwards compatible and easy to implement at the RBS

• Disadvantages
  – Can only be deployed for low traffic
  – Result in marginal EE gains
System-Level Energy Saving: Spatial domain

- Time and frequency domain approaches are employed in a single RBS
- Spatial domain the solutions can be extended to heterogeneous networks, and are therefore more flexible
  - Reduce the Antenna Number
  - Switch On/Off Cells
  - Layered Structure (Heterogeneous Networking)
System-Level Energy Saving: Spatial domain

• Reducing the antenna number
  – The most commonly used energy saving technique in the spatial domain
  – Can be used when the traffic load of a cell is low
  – Advantages
    • Decreases the total output power and shrinks the cell size
    • For example, if the branches of antennas are reduced from 4 to 1, energy consumption of transceivers is reduced to 1/4, as the PAs associated with those branches can be switched off
  – Disadvantages
    • Need to boost the power of RSs and control signals so as to maintain the cell size
    • May lead to service degradation or interruption as the antenna reconfiguration is needed
    • The change of the antenna number should notify UEs properly
System-Level Energy Saving: Spatial domain

- **Switch On/Off Cell**
  - A system-level approach that works in an area covered by multiple (and overlapping) cells
    - When the traffic load in a given area is low, some cells can be shut down, and the served UE units are handed over to the remaining cells
    - Those inactive cells can be turned on during the busy time autonomously or based on signals by active neighbor cells or from the core network (OAM module)
  - **Advantages**
    - Attains maximum energy saving
    - No need to modify the low-layer components in the RBS
    - Provides a good balance between network performance and energy saving
  - **Limitations**
    - Frequent switching on/off cells affects the UE services
    - Reduce the battery life of the served UEs as they have to connect with other cells far away (Reduced network density)
    - If there is no overlapping between cells, the remaining active cells need to increase their power to cover this area, (perhaps) neutralizing the energy saving gain
System-Level Energy Saving: Spatial domain

• Layered Structure
  – Applies to heterogeneous multi-tier networks
    • Prioritized access to low-power nodes
      – E.g., prioritized access to the femtocell station
  – Advantages
    • Provides energy saving opportunities for the RBS of higher layers
      – More energy consuming in general
    • Prolongs the UE battery lifetime
      – Lower tiers are typically characterized by low-power operation and short cell radii
  – Disadvantages
    • Requires for more sophisticated admission control and mobility management algorithms
      – Lower tiers are characterized by random deployment and short cell radii
System-Level Energy Saving: Hybrid Solutions

- Hybrid solutions
  - Combine solutions in different domains to adapt energy consumption of an RBS in different traffic conditions
  - Achieve the highest ES gain
  - Ask for increased processing/interruption time and signaling for system reconfiguration
  - Need to anticipate their impact on the UE performance
System-Level Energy Saving: Research Directions

• Account for the total energy consumed in the life-cycle of the system
  – Include the energy consumed in the use phase of a system and the energy used to manufacture telecom equipment

• Investigate the impact of introducing any new architecture and device to the overall EE improvement
  – The optimization of EE at one point of the system may lead to suboptimal results at other points

• Attain a good trade-off between optimizing the QoS performance and achieving high energy saving gains
  – The improvement of EE should not compromise the supported QoS
System-Level Energy Saving: Research Directions

• Propose comprehensive energy consumption models
  – Capture the key variables of a system regarding energy consumption while providing sufficient abstraction

• Use appropriate metrics to evaluate the performance of the proposed ES technique
  – The EE metric is normally defined as a performance per unit of energy, and the performance typically refers to throughput
  – Capture the provided QoS by accounting QoS measures other than the end throughput

• Optimize the functionality of the system under a EE perspective
  – The EE problem at the system level can be modeled as a joint optimization problem which takes into account resource allocation in time, frequency and spatial domain
Thanks for your kind attention!

Questions?

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