Cell Spectral Efficiency of LTE-Advanced Relay-Enhanced Cells

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• Motivation

• Calculation of Spectral Efficiencies
  • Peak Spectral Efficiency
  • Cell Spectral Efficiency

• Results for LTE-Advanced Relaying

• Conclusion & Outlook
Motivation

• ITU-R invited organizations to submit 4G (IMT-Advanced) wireless mobile systems to supersede 3G

• 3GPP submitted system proposal LTE-Advanced and self-evaluation report

• Independent Evaluation of proposals
  – Evaluated by 13 groups
  – ComNets is part of WINNER+ evaluation group
  – 12 evaluation criteria
Evaluation of IMT-Advanced criteria

• Peak Spectral Efficiency
  – Foundation for cell spectral efficiency

• Cell Spectral Efficiency
  – Determined by system level simulation
  – Path loss model with randomized LoS/NLoS link conditions

➤ An analytical model for the downlink CSE is developed
Peak Spectral Efficiency Calculation

- FDD/TDD
- Overhead for
  - Reference Signals, Synchronization
  - PBCH, PDCCH
  - PRACH, PUCCH
- MIMO
  - 4x4 (DL)
  - 2x2 (UL)
Peak Spectral Efficiency

- Minimum overheads, 64QAM-1/1, 4x4 MIMO (DL), 2x2 (UL), perfect channel

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<th></th>
<th>DL</th>
<th>UL</th>
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Cell Spectral Efficiency

- CSE depends on achievable SINR; from SINR derive throughput

\[ \text{THR}_{L3} = (1 - \text{FER}) \cdot \text{THR}_{MAC} \]
SINR Calculation including (N)LOS probability

- Downlink SINR depends on received power of serving cell and all interferers
- Pathloss
  - Either LoS or NLoS link depending on probability conditional on distance \( d \)
  - Shadowing and Fast-fading effects not taken into count
SINR Calculation including (N)LOS probability

- Downlink SINR depends on received power of serving cell and all interferers
- For a given set $j$ of (N)LOS conditions the SINR is given by

$$SINR_j(x,y) = \frac{P_{Rx,LoS}(d_{ServingCell})}{P_{Rx,LoS}(d_1) + P_{Rx,LoS}(d_2) + \ldots + P_{Rx,LoS}(d_{57}) + \eta}$$

- Random (N)LOS conditions results
  - Random Serving Cell
  - Randomized Interference
Analytical Model

- Idea: compute all permutations and determine exact mean SINR
  \[\text{perm}_j = (p_{j,1}, p_{j,2}, \ldots, p_{j,M-1}, p_{j,M}), \quad j = 1 \ldots 2^M\]

- Necessity to weight the permutation by its occurrence probability
  \[p_{\text{perm},j} = \prod_{i=1}^{M} p_i \quad \forall j\]

- Mean SINR
  \[SINR(x,y) = \sum_{j \in \Psi} p_{\text{perm},j} \cdot SINR_j(x,y)\]
Complexity Reduction

- Consider only one tier of interferers
  - Small impact of second tier on SINR in full load

- Evaluation of one cell in center site

- Reduce number of permutations
  - Assume NLoS link for non-permutable radio access points to derive an upper bound
  - Error analysis available
Impact of Reduced Number of Cells

• Simulations show low impact on SINR from reduced number of cells
Frequency Reuse Schemes

- LTE was designed to support reuse-1 power schemes
- Use power mask to alter reuse schemes
  - Split resources in partitions with different power levels
Cell Spectral Efficiency Results

- LTE-R8 SISO, No Relays
- Capacity according to

\[ \frac{1}{C_{\text{bit}}^{\text{cell}}} = \frac{1}{A_{\text{cell}}} \sum_{x,y} \frac{1}{\text{bpsym}(x,y)} \]

- Spectral Efficiency

\[ CSE = \frac{C_{\text{bit}}^{\text{cell}} C_{\text{net}}}{B} \]

- Requirement: 2.2 bps/Hz/cell
• LTE-Advanced supports Relaying for capacity enhancement and coverage extension
  – Position at 3/4\textsuperscript{th} of the cell radius
  – 256QAM wireless backhaul, error free conditions
  – Cell capacity according to $\frac{1}{C_{\text{composite}}} = \frac{1}{C_{\text{hop1}}} + \frac{1}{C_{\text{hop2}}}$

• Frequency Reuse applied for relays here
  – Base stations and relays use distinct resources
  – Frequency reuse schemes within set of relays
Throughput in Relay Enhanced Cell

- Uniform frequency reuse, one relay per cell
Cell Spectral Capacity for Relay Enhanced Cells

- LTE-A Relaying
- Capacity according to
  \[ CSE = \frac{C_{RN}^{bit} \cdot C_{RN.net}^{bit} + C_{BS}^{bit} \cdot C_{BS.net}^{bit}}{B} \]
- Required: 2.2bps/Hz/cell
Conclusion & Outlook

Conclusions
- Introduction of method to derive cell spectral efficiency analytically
  - Applicable to arbitrary scenarios, not only ITU-R M.2135
  - Supports probabilistic LOS/NLOS links
  - Supports frequency reuse schemes, and antenna patterns
- LTE-Advanced fulfills Peak Spectral Efficiency requirement
- Resource Partitioning between Relays needed if more than 1 Relay per sector is deployed

Outlook
- Include realistic model of the wireless backhaul
- Investigate Cell Edge User performance gains
- Optimize deployments (ISD, downtilt vs. relay distance, etc.)
Thank you for your attention!

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