Inter-cell Interference Coordination Schemes via Homo/Hetero-geneous Network Deployment for LTE-Advanced

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  - Category on downlink CoMP transmission
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  - HetNet & operation principle

- **Summary**
Introduction of 3GPP LTE-Advanced
LTE-Advanced (LTE-A)

- Enhancement of release 8 LTE (Rel.8 LTE)
  - To be specified as release 10 and beyond

- Proposed as a candidate of IMT-Advanced (IMT-A) to ITU-R
  - satisfying IMT-A requirements is one of main targets

**Time table of each LTE release**

<table>
<thead>
<tr>
<th>Year</th>
<th>Rel.8 LTE</th>
<th>Rel.9 LTE</th>
<th>Rel.10 LTE</th>
<th>Rel.11 LTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>Study Item</td>
<td>Work Item</td>
<td>CR</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>WI</td>
<td>CR</td>
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<td>WI</td>
<td>CR</td>
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<tr>
<td>2008</td>
<td>WI</td>
<td>CR</td>
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<td></td>
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<tr>
<td>2009</td>
<td>WI</td>
<td>CR</td>
<td></td>
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<tr>
<td>2010</td>
<td>WI</td>
<td>CR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>WI</td>
<td>CR</td>
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</tbody>
</table>

Feasibility study phase of candidate technologies for LTE-Advanced

Down selection & Specification phase
Rel.8 LTE air interface

- Intra-cell orthogonal multiple access
  - DL: OFDMA
    - High commonality with
      - frequency domain scheduling
      - MIMO
  - UL: SC-FDMA
    - Low PAPR property
      - Maximize coverage

- Support of scalable bandwidth (1.4/3/5/10/15/20MHz)
- Peak data rate
  - DL: 300 Mbps, UL: 75 Mbps (by highest UE category)
- MIMO multiplexing
  - Support up to 4 transmission layers in DL
- Optimized for packet-switching (PS) mode
  - VoIP capability supported
  - Latency reduction on handover, data transmission, etc.
- Application of key techniques for packet radio access
  - Frequency domain scheduling, AMC, Hybrid ARQ, etc.
### IMT-A & LTE-A requirements

<table>
<thead>
<tr>
<th></th>
<th>Downlink</th>
<th></th>
<th></th>
<th>Uplink</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak data rate [Mbps]</td>
<td>300 (4x4)</td>
<td>(1000)</td>
<td>1000</td>
<td>75 (1x2)</td>
<td>(500)</td>
<td>500</td>
</tr>
<tr>
<td>Peak spectrum efficiency [bps/Hz/cell]</td>
<td>15 (4x4)</td>
<td>15</td>
<td>30</td>
<td>3.75 (1x2)</td>
<td>6.75</td>
<td>15</td>
</tr>
<tr>
<td>Average cell throughput [bps/Hz/cell]</td>
<td>1.69 (2x2)</td>
<td>2.2 (4x2)</td>
<td>2.4 (2x2)</td>
<td>0.74 (1x2)</td>
<td>1.4 (2x4)</td>
<td>1.2 (1x2)</td>
</tr>
<tr>
<td>Cell edge user throughput [bps/Hz/cell/UE]</td>
<td>0.05 (2x2)</td>
<td>0.06 (4x2)</td>
<td>0.06 (4x2)</td>
<td>0.07 (2x2)</td>
<td>0.04 (1x2)</td>
<td></td>
</tr>
</tbody>
</table>

- Rel.8 LTE already satisfies some IMT-A requirements
- Higher requirements were set for LTE-A in 3GPP

[Source: 3GPP TR25.912]
Candidate technologies

Relation between requirements and candidate techniques for LTE-Advanced

Requirements
- Backward Compatibility
- Peak data rate
- Peak spectrum efficiency
- Average cell throughput
- Cell-edge user throughput
- Coverage Extension
- Cost Efficient Deployment

Candidate Technologies
- Band Extension (~100MHz)
- DL MIMO Enhancement (~8x8)
- UL MIMO support (~4x4)
- Coordinated Multi-point Tx/Rx
- Relay

Extending the coverage
Providing Higher data rates

Continuously serve higher data rate communication
CoMP:
Coordinated Multi-Point transmission and reception

- Introduction: CoMP transmission/reception
- Category on downlink CoMP transmission
  - Further categorization of JT (in 3GPP)
- Limiting factor for supporting CoMP transmission
- Examples of system performance evaluation
CoMP transmission/reception

**CoMP**

- so-called “distributed MIMO” or “network MIMO”
- Providing MIMO transmission/reception by geographically separated transmission points
  - i.e. Dynamically coordinating among multiple geographically separated transmission/reception points
- Assuming frame timing synchronization among cells
- CoMP has been actively considered in 3GPP, esp. DL CoMP transmission
Category on downlink CoMP transmission

1. **Joint Processing (JP)**
   - Data to a single UE is simultaneously transmitted from multiple transmission points (*CoMP transmission points*)
     - turn destructive inter-cell interference (ICI) into a constructive signal among neighboring cells
   - Sub-categories
     - Joint Transmission (JT)
     - Dynamic cell selection (DCS)

2. **Coordinated beamforming/Scheduling (CB/CS)**
   - Data to single UE is only available at serving cell and transmitted from the serving cell
   - Scheduling/weight decision are made in coordinated fashion among cooperating points.
     - intelligently mitigate destructive inter-cell interference

These schemes ➔ Enabling more spectrum efficient transmission
Further categorization of JT (in 3GPP)

- **Coherent Joint Transmission:**
  - Coherently combine amplitude and phase of data signals sent from all transmission points.
  - Precoding vectors are obtained based on single optimization problem from CSI to all cooperative antennas.
  - Maximized received SINR,
  - Requiring higher capacity and smaller latency of the backhaul for coordinating transmission points

- **Non-coherent Joint Transmission:**
  - Non-coherently combine amplitude and phase of data signals, but still sub-optimal gain can be obtained.
  - Optimized precoding vectors are (typically) selected with assuming a single point transmission using partial CSI.
  - Sub-optimal received SINR gain,
  - Requirements to the backhaul can be alleviated,
  - More robust to the aging of CSI compared to coherent-JT
Limiting factors for supporting CoMP transmission

- Coordination among a large number of transmission points
  - providing a significant increase in cell-edge and cell throughput.

- In practical conditions, the following limiting factors (impairments) restrict CoMP performances
  1. Backhaul capacity and latency
  2. Uplink CSI feedback overhead
  3. Reference signal structure

- These are also important factors for CoMP scheme consideration and selection
1. Backhaul capacity and latency

- The following information has to be shared across cooperating points via “backhaul”:
  - Scheduling information, CSI, Beamforming weight, Data, etc.

- Higher number of cooperating points
- Large amount of CSI

Trade-off between
- system performance gain by CoMP and
- performance degradation due to the backhaul limitation has to be carefully considered.

<table>
<thead>
<tr>
<th>Node type</th>
<th>Backhaul</th>
<th>Latency</th>
</tr>
</thead>
<tbody>
<tr>
<td>eNB</td>
<td>Legacy backhaul</td>
<td>20 msec (typical)</td>
</tr>
<tr>
<td></td>
<td>Advanced backhaul</td>
<td>A few msec</td>
</tr>
<tr>
<td>RRE</td>
<td>Optical fiber</td>
<td>Several μsec</td>
</tr>
<tr>
<td>Relay Node</td>
<td>Wireless backhaul</td>
<td>Several tens msec</td>
</tr>
<tr>
<td>Home eNB</td>
<td>Backhaul via internet</td>
<td>Up to ISP (a few second)</td>
</tr>
</tbody>
</table>
2. Uplink CSI feedback overhead

- CoMP transmission requires CSI:
  - the radio channels of the serving cell
  - The radio channels of all/some cells within the cooperating transmission points

- CoMP transmission is typically applied to UEs located close to a cell bounded

- For TDD operation
  - Uplink sounding reference signal could be utilized to calculate CSI for CoMP Tx due to channel reciprocity

Smaller amount of CSI and CSI feedback algorithms with robustness against aging of the CSI have to be considered.

Minimizing the number of the CSI feedback option is also important requirements to avoid unnecessary test effort.
3. Reference signal structure design

- **Reference signal structure affects**
  - Channel quality estimation accuracy
  - Channel estimation accuracy for demodulation
  - Radio resource consumption/Signaling overhead

- **Support of two types of RS was agreed**
  - **Demodulation RS (DRS)**
    - Transmitted to a specific UE
    - Intend for data demodulation
    - DRS can be precoded with the same precoding matrix applied to data part
  
  *This aspect can reduce the signaling overhead of the scheduling information*

  - **CSI RS**
    - Common RS transmitted to all UEs in a cell
    - For CSI generation

- **Exact format/pattern of the RSs are under consideration**
Examples of system performance evaluation

- Joint transmission (LGE, R1-101355)
- Coordinated beamforming (Motorola, R1-101130)
Coherent joint transmission

- **Super cell set:** cells belong to single eNB (i.e. 3 sectors per eNB)
  - No delay is concerned in terms of CSI sharing
  - SLNR criteria can be applied as MU-MIMO on super cell set

- Precoding vectors are obtained based on effective channel on super cell set
  - Effective channel for j-th UE on f-th sub-carrier:
    \[
    h_{ij}^{\text{eff}}(f) = u(f)H_j(f),
    \]
    \[
    H_j(f) = \begin{bmatrix}
    H_{0j}(f) & H_{1j}(f) & H_{2j}(f)
    \end{bmatrix}
    \]
  - where \( u(f) \) is a receiver side beamforming and \( H_{ij}(f) \) is channel matrix for i-th cell
  - SLNR based precoding for j-th UE based on effective channel:
    \[
    v_j = \arg \max_{\{w\}} \left( \frac{w^{\top} \overline{R}_j w}{\sum_{l \neq j} w^{\top} \overline{R}_l w + L \alpha} \right),
    \]\n    where \( \overline{R}_j \) is covariance matrix scaled by SINR \( \gamma_j \), namely
    \[
    \overline{R}_j = \gamma_j \left( h_j^{\text{eff}} \right)^{\top} h_j^{\text{eff}},
    \]
JT example – LG, R1-101355 (2/2)

System level performance

- **High traffic load scenario**

<table>
<thead>
<tr>
<th></th>
<th>Ideal codebook</th>
<th>6 bits codebook</th>
<th>4 bits codebook</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avg. cell SE (bps/Hz/cell)</td>
<td>5% tile UE SE (bps/Hz/UE)</td>
<td>Avg. cell SE</td>
</tr>
<tr>
<td>MU-MIMO</td>
<td>3.59</td>
<td>0.116</td>
<td>3.42</td>
</tr>
<tr>
<td>MU-JT</td>
<td>3.58(-1%)</td>
<td>0.149(28%)</td>
<td>3.34</td>
</tr>
</tbody>
</table>

  - For 5% tile UE SE 18-28% gain is obtained, while cell average SE is degraded slightly

- **Low traffic load scenario**

<table>
<thead>
<tr>
<th></th>
<th>Ideal codebook</th>
<th>6 bits codebook</th>
<th>4 bits codebook</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avg. cell SE (bps/Hz/cell)</td>
<td>5% tile UE SE (bps/Hz/UE)</td>
<td>Avg. cell SE</td>
</tr>
<tr>
<td>MU-MIMO</td>
<td>2.56</td>
<td>0.343</td>
<td>2.46</td>
</tr>
<tr>
<td>MU-JT</td>
<td>2.70(5%)</td>
<td>0.446(30%)</td>
<td>2.56</td>
</tr>
</tbody>
</table>

  - Both 5% tile UE and cell average SE are improved

JT seems to provide attractive performance improvement in particular below low traffic load scenario with vacant spatial resources
Covariance based coordinated beamforming

- Wideband covariance matrix shared among coordinated cells, intending SLNR criteria with iterative scheduler
  - Impact for signalling overhead would be acceptable
  - Robust for feedback/control delay
  - Possibly extended for inter-eNB coordination

Detailed algorithm
- Precoding matrix for k-th cell is calculated as following

\[ F_k = eig \{ ( \sum_{j \in B_k^{n-1}} \frac{R^k_j}{I_{oj}^{k-1}} + \alpha I)^{-1} R^k_i \} \]

where; \( R^k_j \) implies covariance matrix for j-th UE of k-th cell.
\( I_{oj}^{k-1} \) implies interference observed at j-th UE excluding rx-power from k-th cell and its own serving cell, being updated by equation below as well as tentative UE set (Victim UE set)

- Iterative scheduler updates post-CoMP interference for j-th UE’s measurement set \( B_k^{n-1} \) excluding k-th cell and its own serving cell:

\[ I_{oj}^{k-1} = \sum_{m \in A_j / \{k, s(j)\}} tr(F_m^{H} R_j^{m} F_{m,n-1}) + N_{oj} \]
CB example – Motorola, R1-101130 (2/2)

System level performance

<table>
<thead>
<tr>
<th>Simulation mode</th>
<th>Mean SE (bps/Hz/cell)</th>
<th>5% Cell Edge user SE (bps/Hz/UE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SU/MU-MIMO (non-CoMP)</td>
<td>2.70</td>
<td>0.10</td>
</tr>
<tr>
<td>PF scheduler</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SU/MU+CoBF with inter-eNB CoBF</td>
<td>3.20 (18%)</td>
<td>0.11</td>
</tr>
<tr>
<td>SU/MU with intra-eNB CoBF</td>
<td>2.98 (10%)</td>
<td>0.10</td>
</tr>
<tr>
<td>Modified PF scheduler</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SU/MU+CoBF with inter-eNB CoBF</td>
<td>2.69</td>
<td>0.18 (80%)</td>
</tr>
<tr>
<td>SU/MU with intra-eNB CoBF</td>
<td>2.38</td>
<td>0.17 (70%)</td>
</tr>
</tbody>
</table>

- Coordinated beamforming (CoBF) with PF scheduler provides non negligible mean spectrum efficiency (SE) improvement, in particular with inter-eNB CoBF
- Coordinated beamforming (CoBF) with Modified PF scheduler provides non negligible 5% cell edge user SE improvement, in particular with inter-eNB CoBF

CB seems to provide attractive performance improvement either mean SE or cell edge SE via multi-user scheduling
HetNet: Heterogeneous Network deployment

- Consideration on System capacity
- HetNet & operation principle
- Details on node type for HetNet
Consideration on System capacity

- Additional 428MHz has been assigned for IMT at WRC07 (World Radiocommunication Conference)
- Around 14-15 times traffic increase from 2012 to 2017 of mobile communication systems was estimated*
- Higher user throughput is needed especially in urban area where many users concentrate & at cell-edge
- Heterogeneous network deployment is desired as various network/cell configurations to improve spectrum efficiency/m²

- Feasibility study of enhanced inter-cell interference coordination (eICIC) under HetNet env. has been started since April 2010.

*MIC (Ministry of Internal Affairs and Communications (Japan))
「H20年度情報通信審議会情報技術分科会携帯電話等周波数利用方策委員会報告」
HetNet & operation principle

- Node types composing heterogeneous cell deployment
  - eNBs: connected via traditional or advanced backhaul
  - Remote radio equipments (RRE): directly connected to a central baseband signal processing unit via optical fiber
  - Home eNB (HeNB): connected via high speed internet connection
  - Relay Nodes (RN): connected via wireless backhaul
Details on node type for HetNet

Further detailed characteristics below 3GPP discussion:

- **Access type**: Open or closed subscriber group are served
- **Power setting**: Typical setting depends on intended coverage
- **Placement**: Placed outdoor or indoor depending on major use case

<table>
<thead>
<tr>
<th>Node type</th>
<th>Access</th>
<th>Ex. Power setting for 10MHz</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macro eNB</td>
<td>Open to all UEs</td>
<td>46 dBm</td>
<td>Placed outdoors</td>
</tr>
<tr>
<td>RRE</td>
<td>Open to all UEs</td>
<td>24, 30 (37)</td>
<td>Placed indoors (or outdoors)</td>
</tr>
<tr>
<td>Pico eNB</td>
<td>Open to all UEs</td>
<td>24, 30 (37)</td>
<td>Placed indoors (or outdoors)</td>
</tr>
<tr>
<td>Home eNB</td>
<td>Closed Subscriber Group (CSG)</td>
<td>20 dBm</td>
<td>Placed indoors</td>
</tr>
<tr>
<td>Relay nodes</td>
<td>Open to all UEs</td>
<td>30 dBm</td>
<td>Placed outdoors</td>
</tr>
</tbody>
</table>
Example of HetNet deployment (Macro + Pico)

- **Macro Cell + Pico Cell**
  - Pico cells (small cells) are deployed over Hotzones (area with a high concentration of UEs) to
  - Transmission power of UEs and base stations can also be reduced. More radio resources can be allocated to a single UE.
    - Spectrum efficiency per m² would be improved.

Diagram: Pico cell covers Hotzone

- Macro Cell (3 sectors)
- Pico Cell (omni)
- Directory connected to centralized unit by e.g. optical fiber
Summary

- Introduced current status of feasibility study of CoMP in 3GPP
  - Joint Processing and Coordinated Beamforming/Scheduling
    - turn destructive inter-cell interference (ICI) into a constructive signal among neighboring cells or intelligently mitigate destructive inter-cell interference
  - Several limiting factors in practical condition
    - Backhaul capacity and latency, Uplink CSI feedback overhead, Downlink signaling overhead, RS structure, etc.
- Specifying CoMP has been postponed to later release due to limitation of Rel.10 time schedule and for further study.
- Briefly introduced feasibility study of eICIC under Heterogeneous Network deployment
- These seems to be promising technologies to extend the coverage for higher data rate to provide seamless high data-rate services.
Thank you 😊

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