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

Daichi IMAMURA Atsushi SUMASU
Masayuki HOSHINO Katsuhiko HIRAMATSU

Panasonic Corporation

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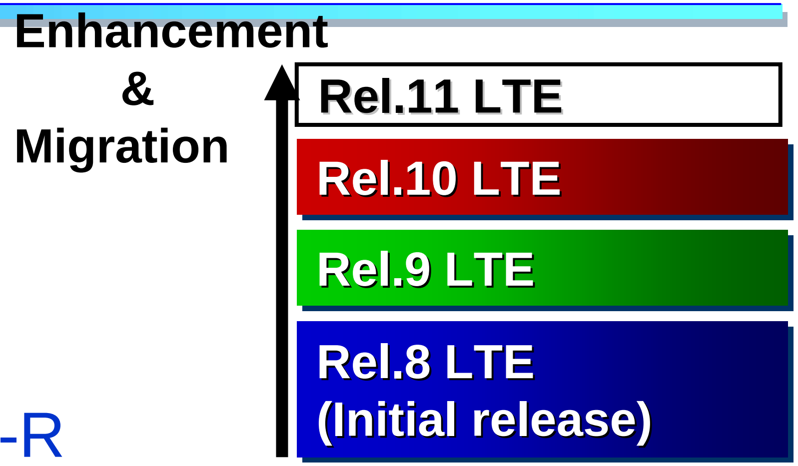
Contents

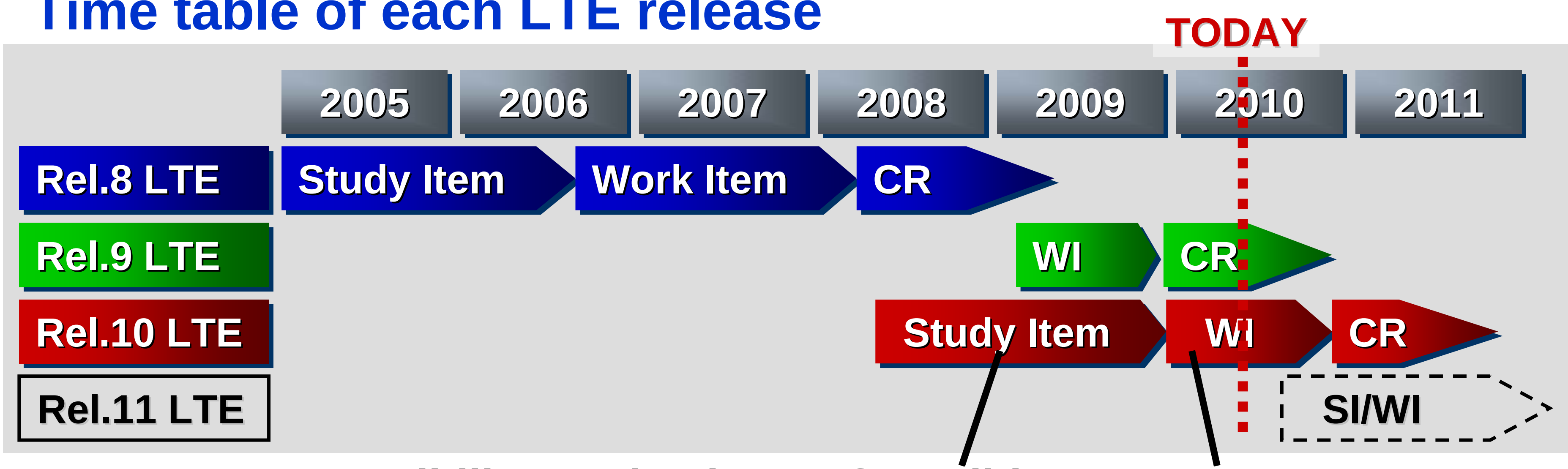
Introduction of 3GPP LTE-Advanced

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

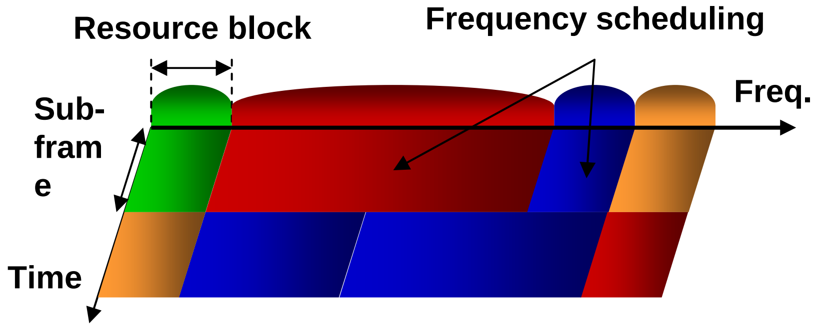


Time table of each LTE release



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

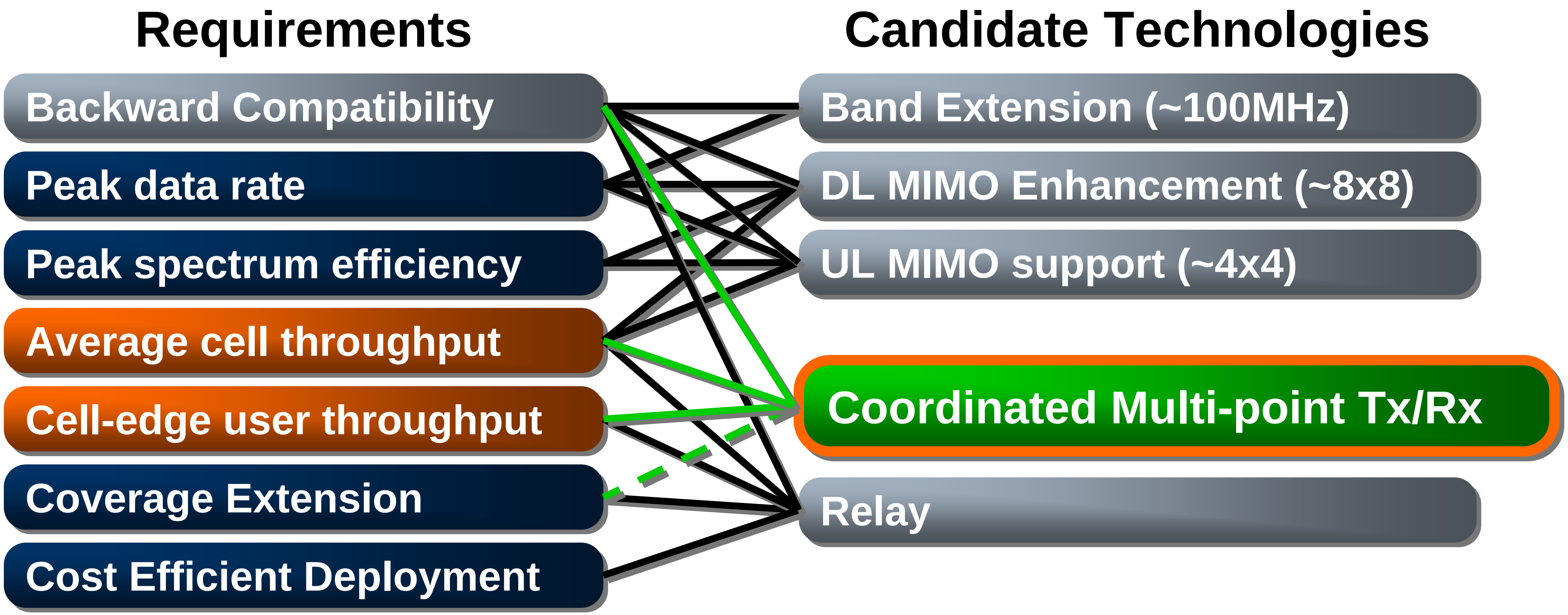
[Source: 3GPP TR25.912]

	Downlink			Uplink		
	Rel.8 LTE	IMT-Adv.	LTE-Adv.	Rel.8 LTE	IMT-Adv.	LTE-Adv.
Peak data rate [Mbps]	300 (4x4)	(1000) x2	1000	75 (1x2)	(500) x4	500
Peak spectrum efficiency [bps/Hz/cell]	15 (4x4)	15	30	3.75 (1x2)	6.75	15
Average cell throughput [bps/Hz/cell]	1.69 (2x2) 1.87 (4x2) 2.67 (4x4)	2.2 (4x2) x1.4~1.6	2.4 (2x2) 2.6 (4x2) 3.7 (4x4)	0.74 (1x2) 1.10 (1x4)	1.4 (2x4) x1.4~1.6	1.2 (1x2) 2.0 (2x4)
Cell edge user throughput [bps/Hz/cell/UE]	0.05 (2x2) 0.06 (4x2) 0.08 (4x4)	0.06 (4x2) x1.4~1.6	0.07 (2x2) 0.09 (4x2) 0.12 (4x4)	0.024(1x2)	0.03 (2x4) x1.4~1.6	0.04 (1x2) 0.07 (2x4)

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

Candidate technologies

- Relation between requirements and candidate techniques for LTE-Advanced



Extending the coverage
Providing Higher data rates

→

Continuously serve higher data rate communication

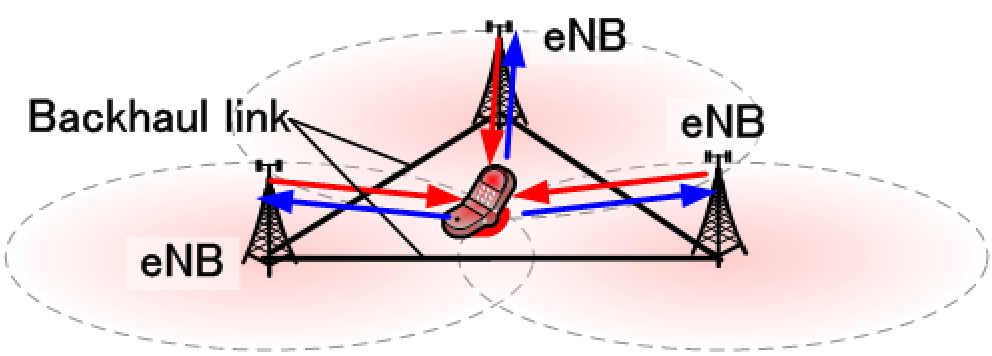
CoMP:
Coordinated Multi-Point transmission and reception

- 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

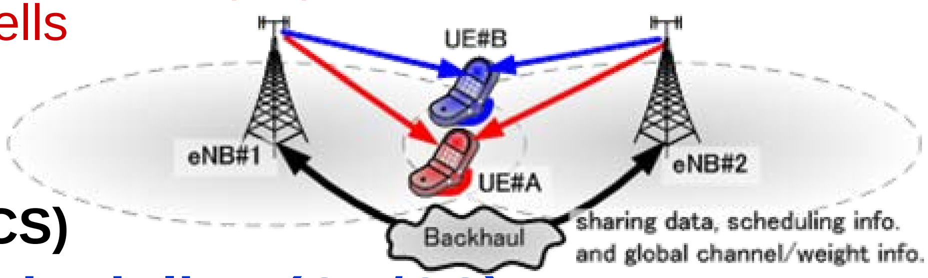
- so-called “distributed MIMO” or “network MIMO”
- Providing MIMO transmission/reception by geographically separated transmission points
  - ➔ i.e. Dynamically coordinating among multiple geographically separated transmission/reception points
- Assuming frame timing synchronization among cells
- CoMP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



Category on downlink CoMP transmission

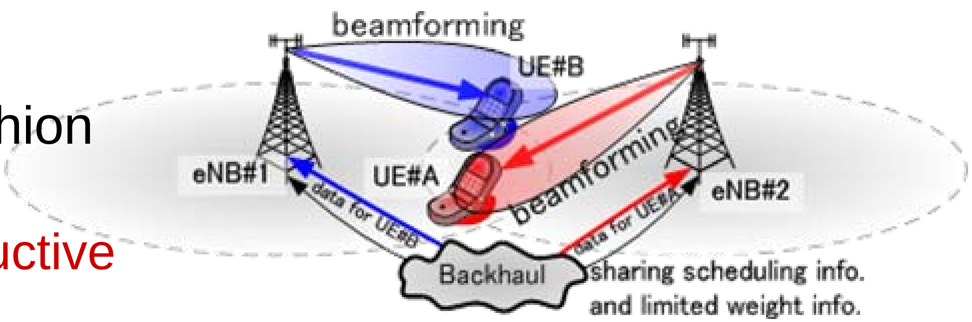
1. Joint Processing (JP)

- 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

→ Higher backhaul capacity and small latency

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

Node type	Backhaul	Latency
eNB	Legacy backhaul	20 msec (typical)
	Advanced backhaul	A few msec
RRE	Optical fiber	Several μsec
Relay Node	Wireless backhaul	Several tens msec
Home eNB	Backhaul via internet	Up to ISP (a few second)

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

Larger amount of CSI feedback

More hardware complexity

Consuming large amount of UL radio resources

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)

JT example – LG, R1-101355 (1/2)

Coherent joint transmission

- **Super cell set:** cells belongs 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:

$$\mathbf{h}_j^{eff}(f) = \mathbf{u}(f)\mathbf{H}_j(f),$$

$$\mathbf{H}_j(f) = \begin{bmatrix} \mathbf{H}_{0j}(f) & \mathbf{H}_{1j}(f) & \mathbf{H}_{2j}(f) \end{bmatrix}$$

channel of cells are concatenated

where $\mathbf{u}(f)$ is a receiver side beamforming and $\mathbf{H}_{ij}(f)$ is channel matrix for *i*-th cell

  - SLNR based precoding for j-th UE based on effective channel:

$$\mathbf{v}_j = \arg\max_{\{\mathbf{w}\}} \left(\frac{\mathbf{w}^H \overline{\mathbf{R}}_j \mathbf{w}}{\sum_{l \in A, l \neq j} \mathbf{w}^H \overline{\mathbf{R}}_l \mathbf{w} + L\alpha} \right),$$

where $\overline{\mathbf{R}}_j$ is covariance matrix scaled by SINR $\overline{\gamma}_j$, namely

$$\overline{\mathbf{R}}_j = \overline{\gamma}_j \left(\overline{\mathbf{h}}_j^{eff}\right)^H \overline{\mathbf{h}}_j^{eff},$$

JT example – LG, R1-101355 (2/2)

System level performance

☐ High traffic load scenario

	Ideal codebook		6 bits codebook		4 bits codebook	
	Avg. cell SE (bps/Hz/cell)	5% tile UE SE (bps/Hz/UE)	Avg. cell SE	5% tile UE SE	Avg. cell SE	5% tile UE SE
MU-MIMO	3.59	0.116	3.42	0.114	3.25	0.110
MU-JT	3.58(-1%)	0.149(28%)	3.34	0.143	3.15	0.130

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

☐ Low traffic load scenario

	Ideal codebook		6 bits codebook		4 bits codebook	
	Avg. cell SE (bps/Hz/cell)	5% tile UE SE (bps/Hz/UE)	Avg. cell SE	5% tile UE SE	Avg. cell SE	5% tile UE SE
MU-MIMO	2.56	0.343	2.46	0.342	2.37	0.327
MU-JT	2.70(5%)	0.446(30%)	2.56	0.425	2.44	0.397

- 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

CB example – Motorola, R1-101130 (1/2)

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

$$F_k = eig\{(\sum_{j \in B_k^{n-1}} \frac{R_j^k}{I_{oj}^{k-}} + \alpha I)^{-1} R_i^k\}$$

Nulling to victim UEs

where; R_j^k implies covariance matrix for j-th UE of k-th cell.
I_{oj}^{k-} 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:

$$I_{oj}^{k-} = \sum_{m \in A_j / \{k, s(j)\}}^{A_j / \{k, s(j)\}} tr(F_{m,n-1}^H R_j^m F_{m,n-1}) + N_{oj}$$

CB example – Motorola, R1-101130 (2/2)

System level performance

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

- 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*

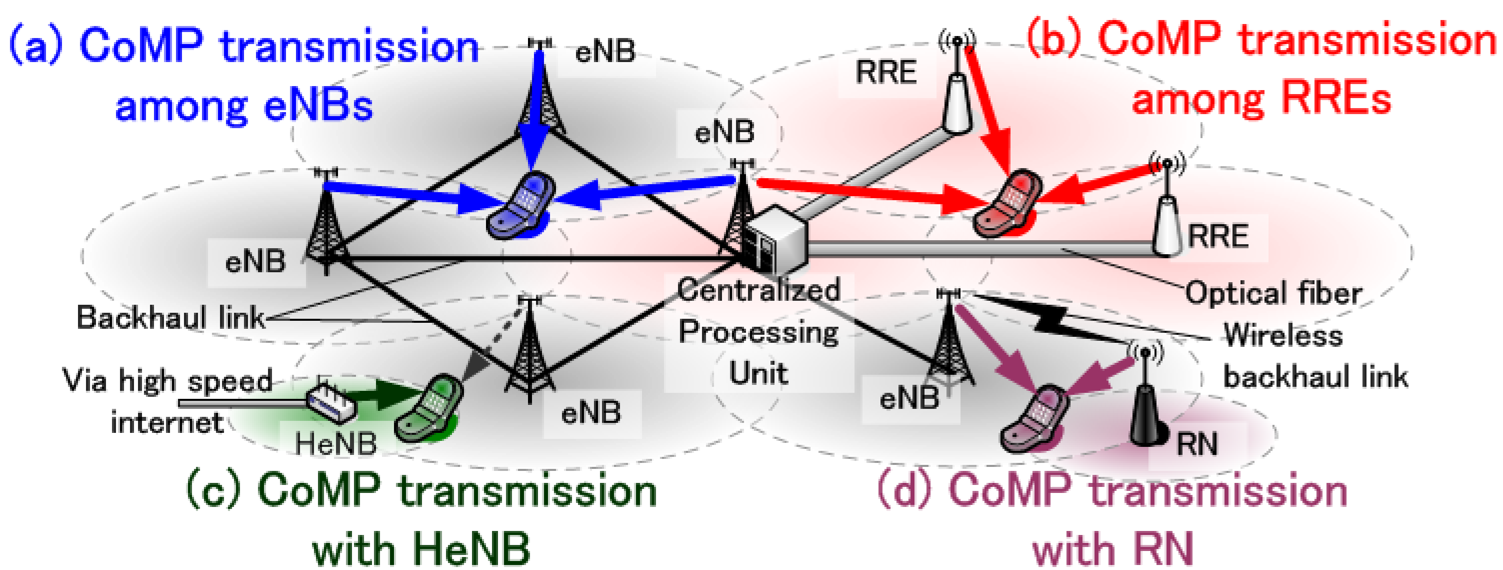
- Higher user throughput is needed especially in urban area where many users concentrate & at cell-edge
- Heterogeneous network deployment is desired as various network/cell configurations to improve spectrum effciency/m^2

- 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

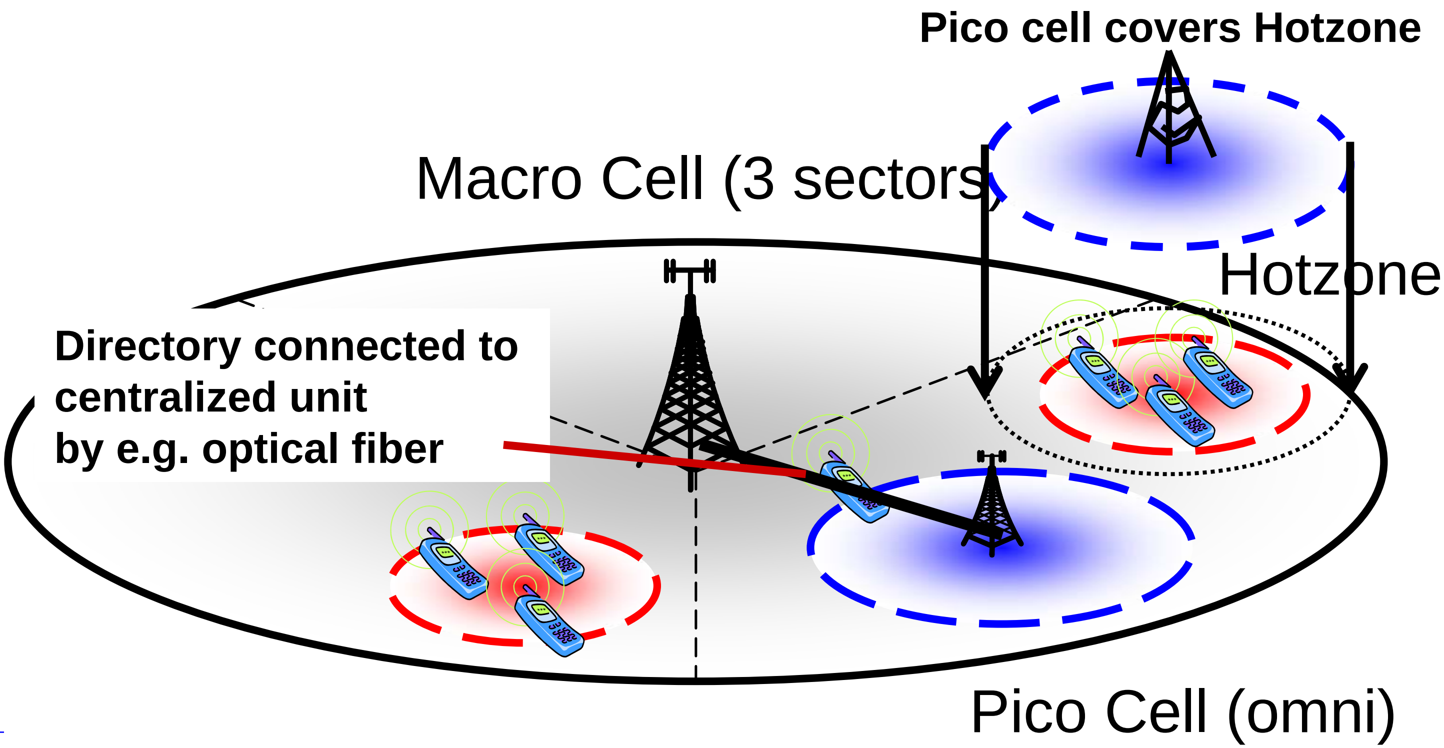
Node type	Access	Ex. Power setting for 10MHz	Notes
Macro eNB	Open to all UEs	46 dBm	Placed outdoors
RRE	Open to all UEs	24, 30 (37)	Placed indoors (or outdoors)
Pico eNB	Open to all UEs	24, 30 (37)	Placed indoors (or outdoors)
Home eNB	Closed Subscriber Group (CSG)	20 dBm	Placed indoors
Relay nodes	Open to all UEs	30 dBm	Placed outdoors

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 m^2 would be improved.



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 ☺

Contact: imamura.daichi@jp.panasonic.com