R1-111288
3GPP TSG WG RAN1 #65
Barcelona, Spain
May 09~13, 2011

Phase 1 CoMP Evaluation Results

Full Buffer

LG Electronics

Scenario 2 – Case 1 Channel Model (4 Tx)

3GPP Case 1	Sector Tput [kbps]	Gain[%]	UE Tput (5%) [kbps]	Gain[%]	Jain Index
SU-MIMO	23069	N/A	699	N/A	0.707
MU-MIMO	25880	N/A	912	N/A	0.751
CS/CB03	27150	4.91%	983	7.81%	0.764
CS/CB09	27339	5.64%	1041	14.14%	0.773
CS/CB57	27842	7.58%	1215	33.26%	0.794
JP3	25802	-0.30%	1095	20.09%	0.805
JP9	25687	-0.75%	1184	29.86%	0.825

Scenario 2 – ITU UMi Channel Model (4 Tx)

ITU UMi	Sector Tput [kbps]	Gain[%]	UE Tput (5%) [kbps]	Gain[%]	Jain Index
SU-MIMO	17411	N/A	473	N/A	0.699
MU-MIMO	21244	N/A	619	N/A	0.699
CS/CB03	22630	6.53%	675	9.01%	0.727
CS/CB09	22771	7.19%	716	15.78%	0.734
CS/CB57	23384	10.08%	863	39.46%	0.764
JP3	22419	5.53%	834	34.86%	0.791
JP9	22453	5.69%	922	49.05%	0.806

Scenario 2 – Case 1 Channel Model (2 Tx)

3GPP Case 1	Sector Tput [kbps]	Gain[%]	UE Tput (5%) [kbps]	Gain[%]	Jain Index
SU-MIMO	18457	N/A	504	N/A	0.699
MU-MIMO	17396	N/A	551	N/A	0.711
CS/CB03	18525	6.49%	619	12.41%	0.734
CS/CB09	18651	7.21%	658	19.51%	0.744
CS/CB57	18978	9.09%	776	40.82%	0.775
JP3	18390	5.71%	722	31.05%	0.782
JP9	18204	4.64%	804	46.05%	0.812

Scenario 2 – ITU UMi Channel Model (2 Tx)

ITU UMi	Sector Tput [kbps]	Gain[%]	UE Tput (5%) [kbps]	Gain[%]	Jain Index
SU-MIMO	14124	N/A	350	N/A	0.682
MU-MIMO	14222	N/A	378	N/A	0.682
CS/CB03	15348	7.91%	428	13.39%	0.724
CS/CB09	15446	8.60%	449	18.79%	0.736
CS/CB57	15874	11.61%	597	58.00%	0.772
JP3	15720	10.53%	548	45.00%	0.803
JP9	15622	9.83%	622	64.61%	0.825

Annex – Simulation Assumptions

- CoMP Set Configuration
- Simulation Parameters
- Scheduling
- CoMP CSCB assumptions
  - UE Feedback
  - eNB computations
- CoMP JT assumptions
  - UE Feedback
  - eNB computations

CoMP Set Configuration

- ☐ Each UE selects CoMP cells within CoMP Cluster
  - CoMP Cluster is defined by cells connected by high speed backhaul (e.g. fiber)
  - UE selects maximum of X number of cells (given in simulation parameter sections)
  - UE feedback information (e.g. PMI, CQI) for maximum of X number of cells

- ☐ Two Metrics of selecting CoMP cells for a given UE
  - RSRP based selection
  - CSI-RS SINR based selection (effects of muting)
    - ✓ Effects: pruning out cells which have low CSI-RS SINR even with muting effects

- ☐ Selection Algorithm
  - Compute selection metric (RSPR and CSI-RS SINR)
  - Sort RSRP metric
  - Select top X number of cells within 10 dB of RSRP metric
    - ✓ If CSI-RS SINR is above -6dB then UE chooses the chosen cells to be CoMP feedback cells

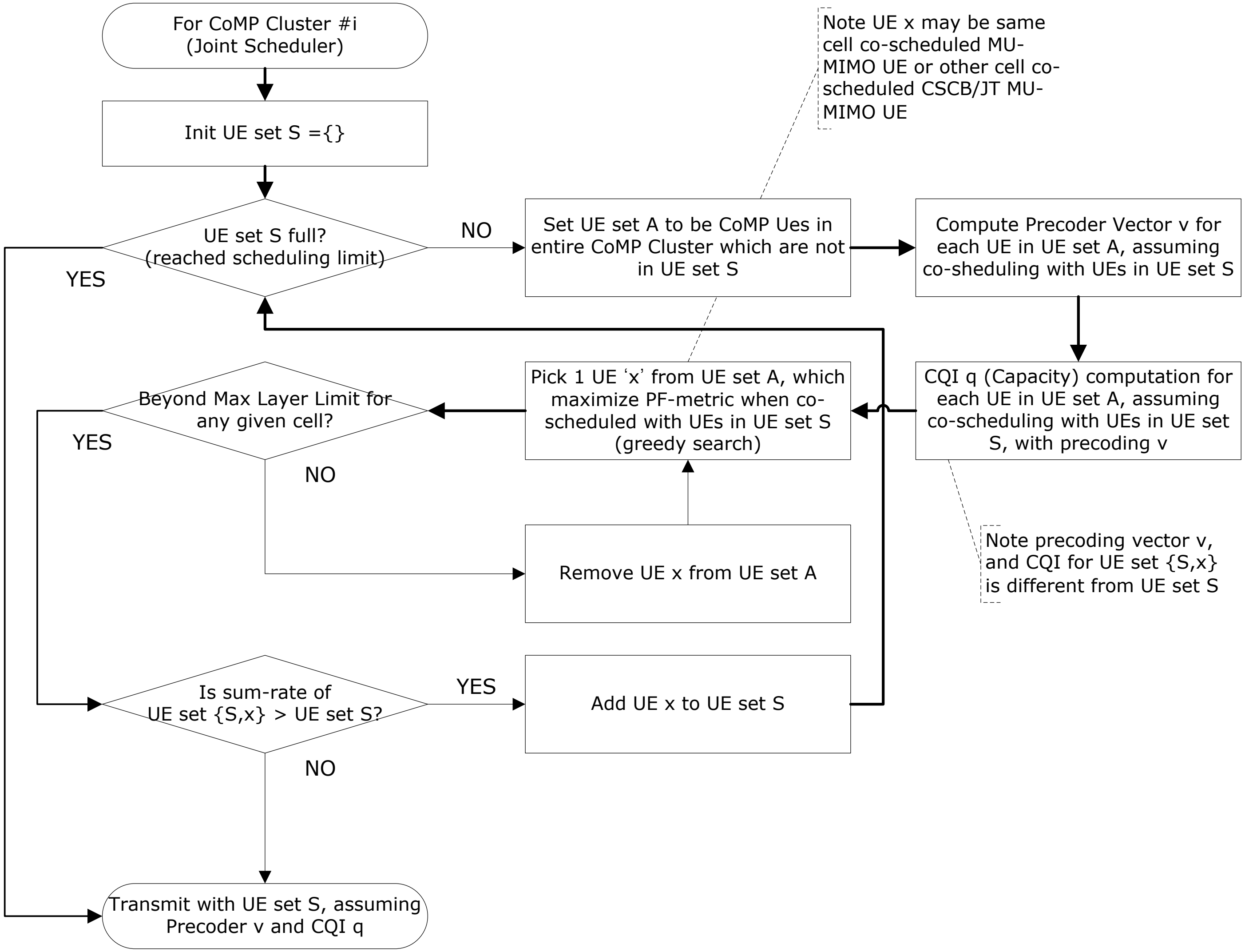
Simulation Parameters (1/2)

Parameters	Assumption
Channel model (Scenario 2, CoMP cluster of 9 cells)	3GPP Case 1 with 3D antenna pattern ITU UMi
System BW	FDD 10MHz
# of UEs, # of cells	(570, 57)
# of antennas at UE, # of antennas at Transmission Point	(2, 4)
Maximum number of feedback set, TP selection RSRP threshold, TP selection CSI-RS quality threshold	(3, 10dB, -6dB)
Antenna configuration	eNB: co-polarized (0.5 spacing) UE: co-polarized antennas
Outer loop for target FER control	10% FER for 1st HARQ transmission
link adaptation	MCSs based on LTE transport formats according to TR 36.213
HARQ scheme	IR
DL overhead	4.2 symbols per RB (3 for PDCCH+1.2 for RS) DRS density: 12RE/RB CRS density: 4/10subframes*6RE/RB
Handover Margin	1 dB
Maximum number of Retransmissions	4
Feedback & Control channel errors	No Error

Simulation Parameters (2/2)

Parameters	Assumption
Scheduler	Greedy search algorithm based on PF metric
Velocity of UEs	3km/hr
Scheduling granularity	Per RB
Traffic load	Full buffer / Non-Full buffer
Maximum Rank per UE	1
Maximum # of SDMA UE per cell	2
Receiver type	MMSE (option 1 of R1-110586)
Channel estimation (DM-RS)	Real
Channel estimation (CSI-RS)	Real
CQI quantization granularity	1.892 dB (4 bits)
Feedback periodicity	5ms
Processing delay (after reception of feedback)	6ms
CQI & CDI feedback granularity	6RB sub band
Codebook for CDI feedback	4bits LTE codebook
Phase corrector among CoMP cell (in JT case)	3 bits (uniform sample of [0 2pi])

Scheduling Algorithm



For CoMP Cluster #i
(Joint Scheduler)

Init UE set S ={}

UE set S full?
(reached scheduling limit)

NO

YES

Set UE set A to be CoMP Ues in entire CoMP Cluster which are not in UE set S

Note UE x may be same cell co-scheduled MU-MIMO UE or other cell co-scheduled CSCB/JT MU-MIMO UE

Compute Precoder Vector v for each UE in UE set A, assuming co-sheduling with UEs in UE set S

CQI q (Capacity) computation for each UE in UE set A, assuming co-scheduling with UEs in UE set S, with precoding v

Note precoding vector v, and CQI for UE set {S,x} is different from UE set S

Pick 1 UE ‘x’ from UE set A, which maximize PF-metric when co-scheduled with UEs in UE set S (greedy search)

Beyond Max Layer Limit for any given cell?

YES

NO

Remove UE x from UE set A

Is sum-rate of
UE set {S,x} > UE set S?

YES

NO

Add UE x to UE set S

Transmit with UE set S, assuming Precoder v and CQI q

UE Feedback – CSCB (1/3)

- Serving cell PMI feedback $\mathbf{p}_{ij}$

$$\mathbf{p}_{ij} = Q\left(rsv\left(\frac{1}{|\mathbf{K}|} \sum_{f\in\mathbf{K}} \left(\mathbf{H}_{ij}(f)\right)^{H} \mathbf{H}_{ij}(f) \right)\right), \qquad \mathbf{u}(f) = \left(\mathbf{H}_{ij}(f)\cdot\mathbf{p}_{\mathbf{ij}}\right)^{H}$$

  - $\mathbf{H}_{ij}(f)$: Channel Matrix Estimate
  - $rsv(\cdot)$: compute right dominant singular vector of matrix
  - **K** : set of subcarriers for a single PMI
  - i : cell index (i should correspond to serving cell)
  - j : UE index
  - $Q(\cdot)$: quantization function (e.g. mapping to codebook entry)

UE Feedback – CSCB (2/3)

- Other cell PMI feedback $\mathbf{p}_{ij}$

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

$$\mathbf{p}_{ij} = Q\left(rsv\left(\frac{1}{|\mathbf{K}|} \sum_{f \in \mathbf{K}} \left(\mathbf{h}_{ij}^{eff}(f)\right)^{H} \mathbf{h}_{ij}^{eff}(f) \right) \right),$$

  - **H**$_{ij}$(*f*) : Channel Matrix Estimate
  - **u**(*f*) : receive processing filter
  - *rsv*(·) : compute right dominant singular vector of matrix
  - **K** : set of subcarriers for a single PMI
  - i : CoMP feedback cell index, i should correspond to non-serving cells
  - j : UE index
  - Q(·) : quantization function (e.g. mapping to codebook entry)

UE Feedback – CSCB (3/3)

- CQI feedback (Rank 1) $\bar{\gamma}_{ij}$

$$\gamma_{ij}(f) = \frac{\left|\mathbf{u}(f)\mathbf{H}_{ij}(f)\mathbf{p}_{ij}\right|^2}{N(f)},$$

$$\bar{\gamma}_{ij} = Q\left(g^{-1}\left(\frac{1}{|\mathbf{K}|}\sum_{f\in\mathbf{K}} g\left(\gamma_{ij}(f)\right)\right)\right),$$

  - $N(f)$: average noise and interference power from other CoMP clusters (e.g. group of cells)
  - $g(\cdot)$: PHY abstraction of effective SINR mapping function
  - **K** : set of subcarriers for a single CQI
  - Q(·) : quantization function (e.g. mapping to CQI level)

Scheduling – CSCB (1/3)

- ☐ Precoder Vector Computation $\mathbf{v}_{ij}$
  - MMSE whitened precoding based method

$$\mathbf{v}_{ij} = \left(\sum_{k\in\mathbf{S}} \overline{\mathbf{R}}_{ik} + \mathbf{I}\right)^{-1} \mathbf{p}_{ij} \qquad \overline{\mathbf{h}}_{ik}^{eff} = \sqrt{\overline{\gamma}_{ik}} \cdot \mathbf{p}_{ik}^{H} \qquad \overline{\mathbf{R}}_{ik} = \left(\overline{\mathbf{h}}_{ik}^{eff}\right)^{H} \overline{\mathbf{h}}_{ik}^{eff}$$

- ✓ **S** : set of scheduled UEs in CoMP cluster $\mathbf{S} = \{S_1, S_2, \cdots, S_M\}$
- ✓ S_n : set of scheduled UEs in Cell ‘n’ of the CoMP cluster
- ✓ If ‘k’ UE does not report CSI feedback for cell ‘i’, then $\overline{\mathbf{R}}_{ik} = 0$
- ✓ Precoder vector v_{ij} is normalized with Tx power constrains

Scheduling – CSCB (2/3)

- CQI metric computation (for Rank 1) $\bar{\gamma}_{ij}'$

$$\bar{\gamma}_{ij}' = \frac{\left\|\bar{\mathbf{h}}_{ij}^{eff}\cdot\mathbf{v}_{ij}\right\|_F^2 / L_i}{\sum_{m\in\mathbf{C}}\sum_{k\in S_m}\left\|\bar{\mathbf{h}}_{mj}^{eff}\cdot\mathbf{v}_{mk}\right\|_F^2 / L_m - \left\|\bar{\mathbf{h}}_{ij}^{eff}\cdot\mathbf{v}_{ij}\right\|_F^2 / L_i + 1}$$

  - **C** : set of cells in CoMP cluster
  - **S**$_m$: set of scheduled UEs in CoMP cluster
  - L$_k$: is the number of scheduled UEs at cell #*k*
  - If ‘k’ UE does not report CSI feedback for cell ‘i’, then $\bar{\mathbf{R}}_{ik} = 0$

Scheduling – CSCB (3/3)

- CQI metric computation (for Rank 2) $\bar{\gamma}_{ij}^{1}{}'$ $\bar{\gamma}_{ij}^{2}{}'$

$$\bar{\gamma}_{ij}^{1}{}' = \frac{\left\|\bar{\mathbf{h}}_{ij,1}^{eff}\cdot\mathbf{v}_{ij,1}\right\|_F^2 / L_i}{\sum_{m\in\mathbf{C}}\sum_{k\in S_m}\left\|\bar{\mathbf{h}}_{mj}^{eff}\cdot\mathbf{v}_{mk}\right\|_F^2 / L_m - \left\|\bar{\mathbf{h}}_{ij,1}^{eff}\cdot\mathbf{v}_{ij,1}\right\|_F^2 / L_i + 1}$$

$$\bar{\mathbf{h}}_{ij}^{eff} = \left[\bar{\mathbf{h}}_{ij,1}^{eff}\ \ \bar{\mathbf{h}}_{ij,2}^{eff}\right]$$

$$\mathbf{v}_{ij} = \begin{bmatrix}\mathbf{v}_{ij,1}\\ \mathbf{v}_{ij,2}\end{bmatrix}$$

$$\bar{\gamma}_{ij}^{2}{}' = \frac{\left\|\bar{\mathbf{h}}_{ij,2}^{eff}\cdot\mathbf{v}_{ij,2}\right\|_F^2 / L_i}{\sum_{m\in\mathbf{C}}\sum_{k\in S_m}\left\|\bar{\mathbf{h}}_{mj}^{eff}\cdot\mathbf{v}_{mk}\right\|_F^2 / L_m - \left\|\bar{\mathbf{h}}_{ij,2}^{eff}\cdot\mathbf{v}_{ij,2}\right\|_F^2 / L_i + 1}$$

- ✓ **C** : set of cells in CoMP cluster
- ✓ S_m : set of UEs in cell ‘m’
- ✓ L_k : is the number of scheduled UEs at cell #*k*
- ✓ If ‘k’ UE does not report CSI feedback for cell ‘i’, then $\bar{\mathbf{R}}_{ik} = 0$

UE Feedback - JT

- PMI feedback $\mathbf{p}_{ij}$

$$\mathbf{H}_j(f)=\left[\mathbf{H}_{1j}(f),\mathbf{H}_{2j}(f),\cdots,\mathbf{H}_{Mj}(f)\right] \qquad \mathbf{u}(f)=\left(\mathbf{H}_j(f)\cdot\mathbf{p}_j\right)^H$$

$$\mathbf{p}_j=Q\left(rsv\left(\frac{1}{|\mathbf{K}|}\sum_{f\in\mathbf{K}}\left(\mathbf{H}_j(f)\right)^H\mathbf{H}_j(f)\right)\right)=\left[\alpha_{1j}\cdot\mathbf{p}_{1j}^T,\quad \alpha_{2j}\cdot e^{j\theta_{2j}}\cdot\mathbf{p}_{2j}^T,\quad \cdots,\quad \alpha_{Mj}\cdot e^{j\theta_{Mj}}\cdot\mathbf{p}_{Mj}^T\right]^T,$$

  - $\mathbf{p}_j$: composite precoding matrix of CoMP cells with quantized phase correction
  - $\mathbf{H}_{ij}(f)$: Channel Matrix Estimate of cell ‘i’ at UE ‘j’
  - α_{kj} : amplitude value of precoding vector of cell ‘k’ for UE ‘j’
  - θ_{kj} : phase value of precoding vector of cell ‘k’ for UE ‘j’
  - **K** : set of subcarriers for a single PMI, i : cell index, j : UE index
  - Q(·) : quantization function (e.g. mapping to codebook entry)
  - M : number of cell in which UE has feedback CSI

UE Feedback - JT

- CQI feedback

$$\gamma_{ij}(f) = \frac{\left|\mathbf{u}(f)\mathbf{H}_{j}(f)\mathbf{p}_{ij}\right|^{2}}{N(f)}$$

$$\bar{\gamma}_{ji} = Q\left(g^{-1}\left(\frac{1}{|\mathbf{K}|} \sum_{f \in \mathbf{K}} g\left(\gamma_{ij}(f)\right) \right) \right),$$

  - *N*(*f*) : average noise and interference power from other CoMP clusters (e.g. group of cells)
  - *g*(·) : PHY abstraction of effective SINR mapping function
  - **K** : set of subcarriers for a single CQI
  - Q(·) : quantization function (e.g. mapping to CQI level)

Scheduling - JT

❑ Precoder Vector Computation

- Based on SLNR maximization criterion

$$\mathbf{v}_j = \left(\sum_{k \in \mathbf{S}, k \neq j} \overline{\mathbf{R}}_k + \mathbf{I} \right)^{-1} \mathbf{p}_j$$

$$\overline{\mathbf{R}}_j = \left(\overline{\mathbf{h}}_j^{eff} \right)^H \overline{\mathbf{h}}_j^{eff} \qquad \overline{\mathbf{h}}_j^{eff} = \left[\sqrt{\overline{\gamma}_{1j}} \cdot e^{j\theta_{1j}} \cdot \mathbf{p}_{1j}^H, \quad \sqrt{\overline{\gamma}_{2j}} \cdot e^{j\theta_{2j}} \cdot \mathbf{p}_{2j}^H, \quad \cdots, \quad \sqrt{\overline{\gamma}_{Mj}} \cdot e^{j\theta_{Mj}} \cdot \mathbf{p}_{Cj}^H \right]$$

✓ **S** : set of scheduled UEs in CoMP cluster

✓ C : number of cells participating in CoMP (within CoMP cluster)

Scheduling - JT

- ❑ Actual CQI (compensated) (Rank 1)

$$\bar{\gamma}_j' = \frac{\left\|\bar{\mathbf{h}}_j^{eff} \cdot \mathbf{v}_j\right\|^2 / L}{\sum_{k \in S, k \neq j} \left\|\bar{\mathbf{h}}_j^{eff} \cdot \mathbf{v}_k\right\|^2 / L + 1}$$

  - ✓ L : is the number of scheduled UEs at CoMP cluster serving UE *j*