

Coordinated Multi-Point (CoMP) Adaptive Estimation and Prediction Schemes using Superimposed and Decomposed Channel Tracking

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Introduction

Motivation:

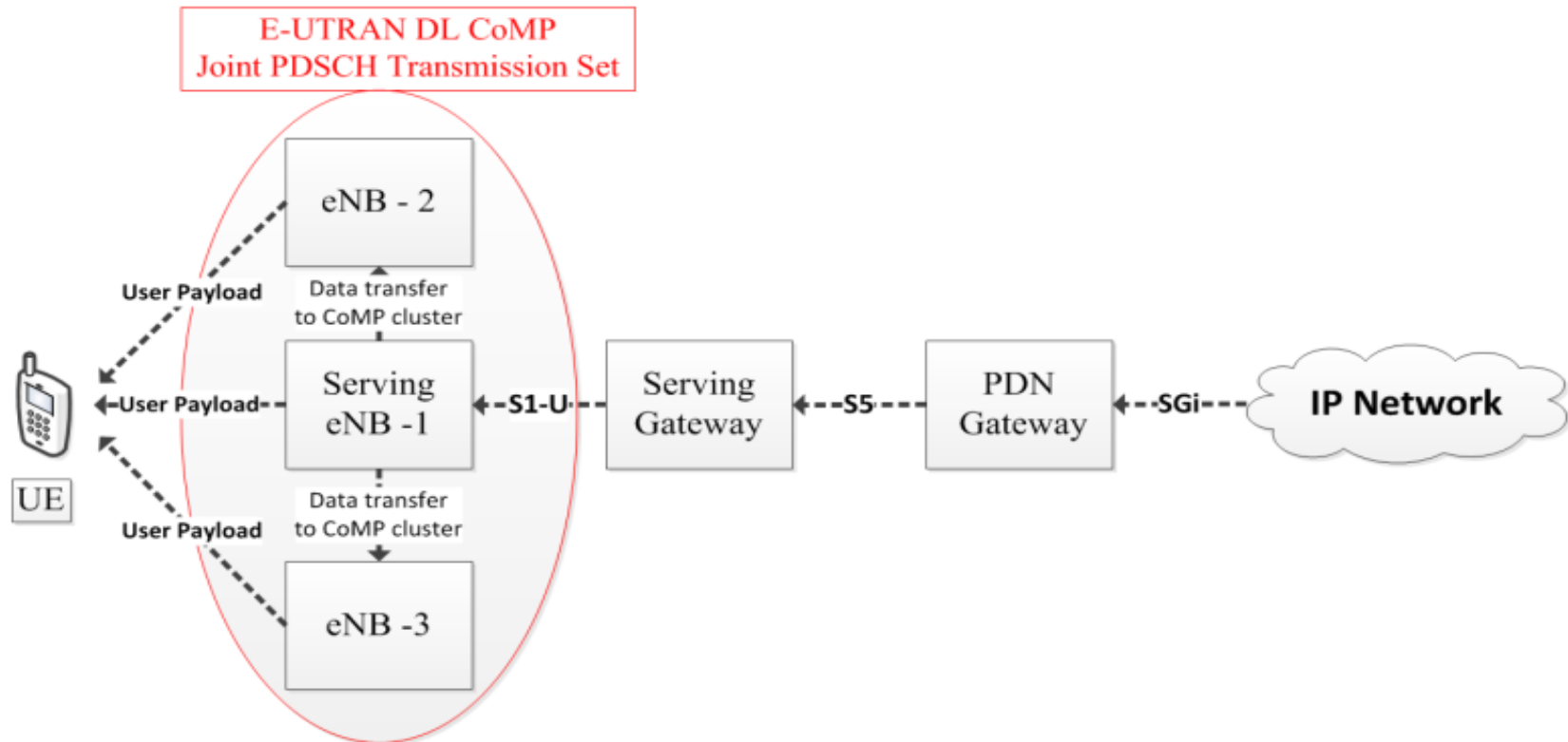
- Comparison of decomposed and superimposed channel tracking methods in Coordinated Multi-Point (CoMP) networks is not studied in existing literature.

Our contributions

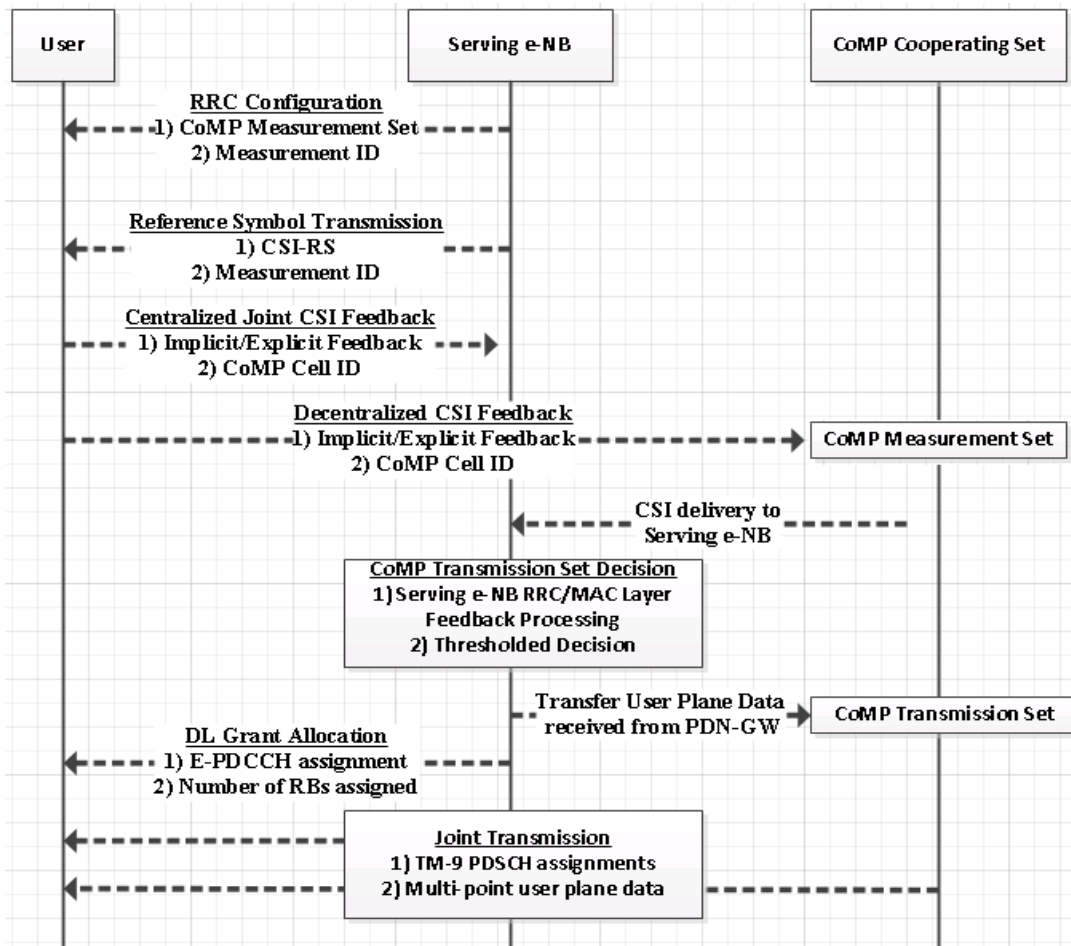
- Multi-point channel estimation and prediction framework to tackle the CoMP system delays and inaccurate measurements
- Comparison between superimposed versus decomposed channel estimation schemes
- CoMP adaptive switching/fallback between channel estimation schemes
- Balance the clustering accuracy versus the channel estimation computation complexity trade-off
- Effects of estimation/prediction filter length increases on CoMP performance are characterized according to users being served by various cluster sizes

CoMP Joint Transmission Procedures

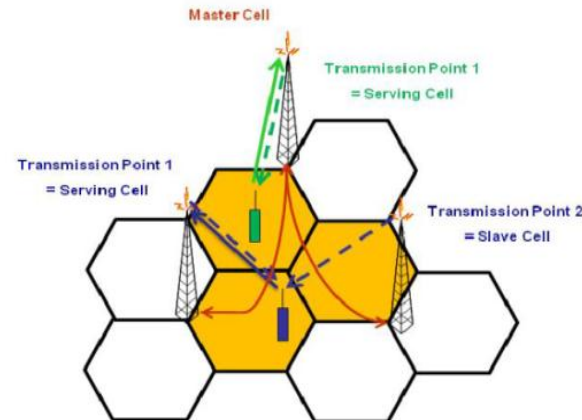
CoMP Definition: Dynamic coordination among multiple geographically separated points referred as CoMP cooperating set for downlink transmission and uplink reception



CoMP Joint Transmission Procedures



Parameter	Assumption or Value
N_{Coop}	CoMP coordinating set
N_{meas}	CoMP measurement set
N_{JT}	CoMP joint transmission set



Threshold Based CoMP Joint Transmission Clustering

- Actual measured received power from eNB n by user i at TTI t :

$$P_{RX}(n, t, i) = P_{TX}(n) - PL(n, i) - P_{Fading}(n, i, t)$$

- Received feedback due to estimation error + system delay:

$$P_{RX_err}(n, t, i) = P_{RX}(n, t - \Delta, i) + P_{err}(\mu, \sigma)$$

- Threshold based Decision to Form the CoMP Transmission Set:

$$n_{Best}(i, t) = \arg \max_n \{ P_{RX_err}(n, i, t) \}$$

$$n \in N_{JT}(i, t) \text{ if } |P_{RX_err}(n_{Best}, i, t) - P_{RX_err}(n, i, t)| \leq \nabla_{NW-JT}$$

Note: Contents of the joint transmission set will be impacted by reported CSI feedbacks due to multi-point channel estimation errors and system delays !!!

CoMP Performance Metrics - Capacity

- Joint PDSCH transmission (TM-9) mitigates the Inter-cell Interference

Single Point Transmission

$$SINR = \frac{P_{serving}}{\sum_{i=1}^K P_i + P_{Noise}}$$

CoMP Downlink Transmission

$$SINR_{CoMP} = \frac{P_{serving} + P_j + P_m}{\sum_{i=1, i \neq j, m}^K P_i + P_{Noise}}$$

Total received Power from CoMP Transmission Set

$$P_{JT}(i, t) = \sum_{n \in N_{JT}} P_{RX}(n, i, t)$$

Perceived Downlink Capacity due to CoMP

$$C(i, t) = W(i, t) \log_2 \left(1 + \frac{P_{JT}(i, t)}{\sum_{n \in N \setminus N_{JT}(i)} P_{RX}(n, i, t) + P_{noise}} \right)$$

CoMP Performance Metrics – Energy Efficiency

CoMP Power Consumption Model

Signal Processing Power	$P_{SP-CoMP} = 58 (0.87 + 0.1N_C + 0.03N_C^2)$
Backhauling Power	$P_{BH} = \frac{C_{BH}}{100Mbits/sec} 50W$
Additional Data capacity for CoMP Backhauling	$C_{BH} = \frac{N_c(2N_C)pq}{T_S} bits/sec$
Total Power Consumption of an eNB using CoMP	$P_{CoMP} = N_s N_{\frac{PA}{sector}} \left(\frac{P_{TX}}{PA_{eff}} + P_{SP} \right) (1 + C_C)(1 + C_{BB}) + P_{BH}$

Power Consumption Parameters

N_s = Number of Sectors $N_{\frac{PA}{sector}}$ = Power amplifiers per sector P_{TX} = DL Transmit Power, C_C = Cooling Loss
 C_{BB} = Battery Backup N_C = Number of points in Joint Transmission p = pilot density q = CSI signalling
 T_S = Symbol Period PA_{eff} = Power Amplifier Efficiency

CoMP Performance Metrics – Energy Efficiency

$$\text{Energy Efficiency} = \frac{\text{Capacity (bits/sec)}}{\text{Power Consumption (Joules/sec)}} = \frac{\text{bits}}{\text{Joule}}$$

Time Varying Energy Efficiency

Joint Transmission CoMP Operation ($N_C \geq 2$)

$$EE(i, t) = \frac{C(i, t)}{P_{CoMP} + (N_{JT(i,t)} - 1)(P_{CoMP} - P_{Base})}$$

Single Point Transmission ($N_C = 1$)

$$EE(i, t) = \frac{C(i, t)}{P_{Base}}$$

Notes:

- 1) P_{Base} has $P_{BH} = 0$ since there is not need for multi-point CSI transfer to serving cell
- 2) $P_{SP-CoMP} = 58W$ since $N_C = 1$

CoMP Performance Metrics Summary

Technical challenges of CoMP systems due to channel estimation errors and system delays:

1. Lowered Joint Transmission Cluster Degree

- Inaccurate multi-point CSI feedbacks can exclude a potential joint transmission point from the CoMP cluster unnecessarily.
- This decreases both the energy efficiency of the access network and the user perceived quality of service in terms of received downlink data rates.

2. Expanded Joint Transmission Cluster Degree

- Inclusion of an incorrect point in the CoMP joint transmission cluster increases the downlink data rates slightly; however, this causes significant bits/Joule energy efficiency losses since the increased power consumption of the access network is not compensated by an equal amount of downlink capacity gain for the served UEs.

Decomposed Channel Impulse Response (CIR) Estimation

- Track each multipath delay tap of every CoMP measurement set member individually
- Perform channel estimation separately for each path
- Smoothened CIR at each path is then merged to report CSI feedback for all points

$$\tilde{h}_{n,i}(t, \tau_l) = \sum_{m=0}^{M_{UE}-1} w(m) \hat{h}(t-m, \tau_l) \quad w(j) > w(k) \quad \forall j < k$$

$$\tilde{h}_{n,i}(t, \tau_l) = [(R_h(\Delta t, \tau_l) + \sigma_{noise}^2 I_{M_{UE} \times M_{UE}})^{-1} r_h(\Delta t, \tau_l)]^H \hat{\mathbf{h}}_{t, \dots, t-M_{UE}+1; \tau_l}$$

$$\hat{\mathbf{h}}_{t, \dots, t-M+1; \tau_l} = [\hat{h}(t, \tau_l) \dots \hat{h}(t - M_{UE} + 1, \tau_l)]^T$$

$$R_h(\Delta t = M_{UE} - 1, \tau_l) = E[h(t - M_{UE} + 1, \tau_l) h(t, \tau_l)^*]$$

Superimposed Channel Impulse Response (CIR) Estimation

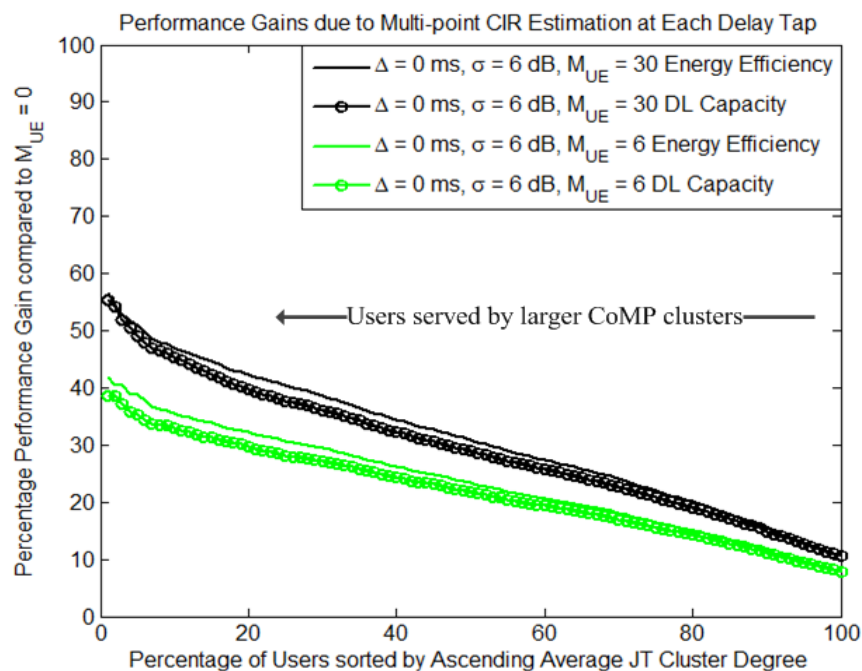
- Track the superimposed time-varying CIR coefficients instead of separate CIR realizations at each path
- Yields less accurate CSI estimates compared to decomposed multipath tracking
- Multi-point channel estimation complexity of the UE is decreased significantly
- Smaller auto-correlation filter and channel estimation filter input buffers

$$\tilde{h}_{n,i}(t) = [(R_h(\Delta t) + \sigma_{noise}^2 I_{M_{UE} \times M_{UE}})^{-1} r_h(\Delta t)]^H \hat{\mathbf{h}}_{t, \dots, t-M_{UE}+1}$$

$$\hat{\mathbf{h}}_{t, \dots, t-M+1; \tau_l} = \left[\sum_{l=1}^L \hat{h}(t, \tau_l), \dots, \sum_{l=1}^L \hat{h}(t - M_{UE} + 1, \tau_l) \right]^T$$

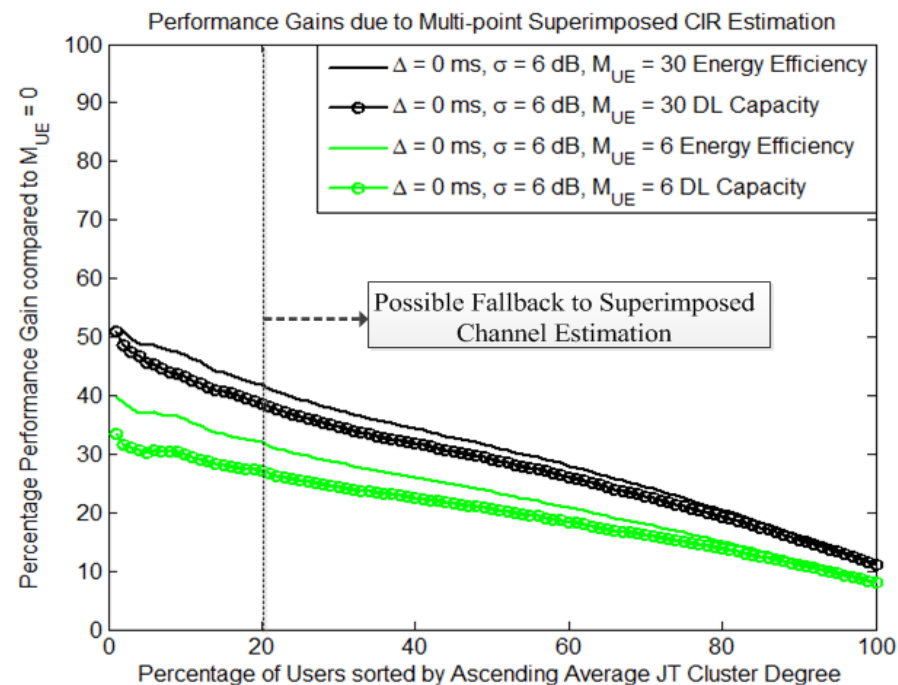
$$R_h(\Delta t) = \int_{l=1}^L R_h(\Delta t, \tau_l) d\tau_l$$

Performance Analysis of Multi-point Channel Estimation Schemes



Decomposed multi-point channel estimation

- Better performance for users being served by large clusters
- Increased computational burden on the UE firmware to track each path separately



Superimposed multi-point channel estimation

- Energy efficiency and capacity degradation for users being served by large clusters
- Faster channel estimation computation time and decreased CSI feedback delay

CoMP Adaptive Channel Estimation Scheme Switching

Superimposed CIR Tracking

- Inputs to the channel estimation filter: Superimposed complex baseband channel impulse response
- Track the summation of the channel samples observed at all the multipath delay taps
- Use the overall time autocorrelation function instead of delay-cross power density

$$\mu_{N_c} < N_{threshold}$$

$$\mu_{N_c} \geq N_{threshold}$$

Decomposed CIR Tracking

- Inputs to the channel estimation filter: CIR samples observed at each multi-path delay tap
- Track CIR samples observed at each delay tap separately
- Use the delay-cross power density instead of overall time autocorrelation function

CoMP cluster degree adaptive switching

- Use Decomposed channel estimation when the wireless device is receiving downlink CoMP joint transmission from a large cluster
- Fallback to superimposed estimation if cluster size decreases

- Define critical measured received power zone as:

$$\nabla_{NW-JT} - Threshold_{P_JT} \leq \Delta_{j,t} \leq \nabla_{NW-JT} + Threshold_{P_JT}$$

$$\Delta_{j,t} = P_{RX}(n_{best}, t) - P_{RX}(n_j, t)$$

$$\nabla_{NW-JT} = \text{NW configured CoMP clustering threshold}$$

$$\nabla_{NW-JT} - Threshold_{P_JT} \leq \Delta_{j,t} \leq \nabla_{NW-JT} + Threshold_{P_JT}$$

YES

NO

Decomposed CIR estimation
for: $n_j \in N_{Meas}(t)$

Superimposed CIR estimation
for: $n_j \in N_{Meas}(t)$

CoMP received power adaptive switching

- UEs increase the channel estimation computation complexity only for the critical points that require extremely accurate CSI feedback for joint transmission set clustering decisions

Multi-Point Channel Impulse Response (CIR) Prediction

Parameter	Representation
$\check{h}_{n,i}$	Predicted CIR samples by the serving e-NB
$\tilde{h}_{n,i}$	Estimated CIR samples by the UE
$p \in [1, \dots, P]$	Prediction range in terms of number of TTIs
M_{NW}	Prediction filter length used by the serving e-NB

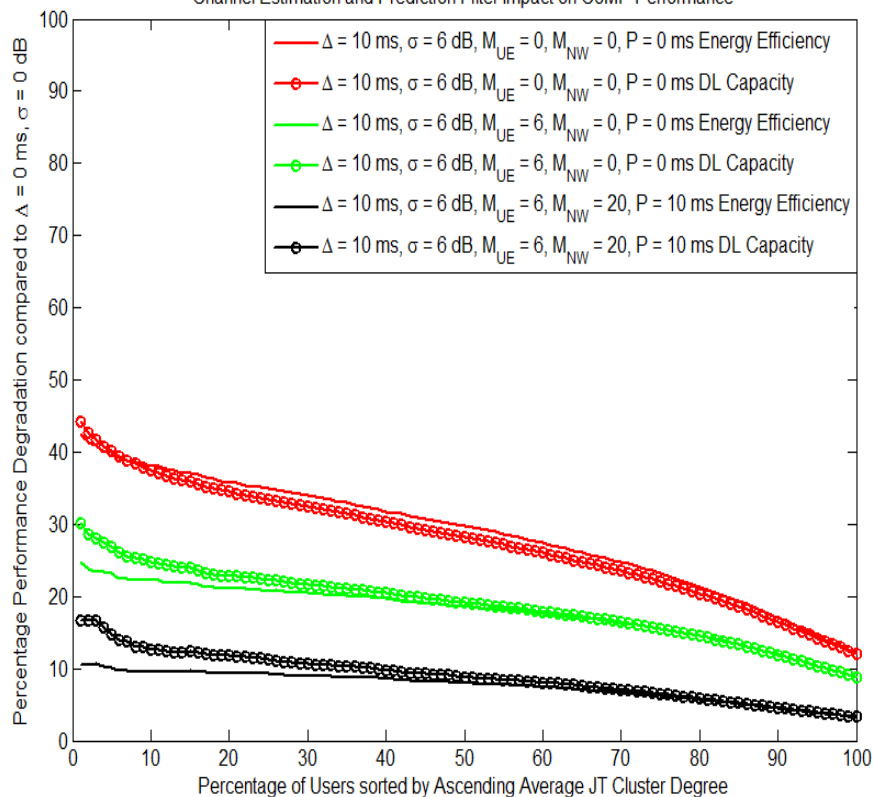
1. Serving e-NB performs the prediction at P steps using:

$$\check{h}_{n,i}(t+p) = \sum_{\substack{m=1 \\ p>1}}^{p-1} \check{h}_{n,i}(t+p-m)w(m) + \sum_{m=p}^{M_{NW}} \tilde{h}_{n,i}(t+p-m)w(m),$$

2. Filter inputs, predicted CIR autocorrelation matrix and filter coefficients are updated at every step
3. Currently predicted CIR sample replaces the most outdated CIR sample for the filter input at each step p

Performance improvement of CoMP systems due to multi-point channel estimation and prediction schemes

Channel Estimation and Prediction Filter Impact on CoMP Performance



- Multi-point channel estimation procedures performed by the UEs are enough to tackle the channel estimation errors
- However, CoMP system delays still create performance degradations due to outdated CSI feedbacks
- Serving e-NB should predict how the multi-point CIRs will change at the time of the joint data transmission
- CIR prediction range P is set to the system delay observed in the channel to maximize the performance gains due to prediction
- Estimation and prediction filter lengths and the prediction ranges should be adapted according to the served UE's CoMP characteristics

CONCLUSION & SUMMARY

- UEs should choose to switch dynamically between the two channel estimation schemes depending on the recently observed CoMP characteristics
- UEs should balance the optimal trade-off between CoMP capacity and energy efficiency performance gains versus computation complexity
- UEs that are being served by larger clusters should use decomposed CIR estimation and tracking, and fallback to superimposed tracking method when the cluster size decreases
- Use decomposed CIR estimation tracking only for the points that have received power values which are close to the joint transmission cluster threshold or for the points that are recently added to the CoMP measurement set

FUTURE WORK

- Utilize CoMP adaptive channel estimation scheme switching method jointly with the CoMP adaptive filter length choices
- Decomposed channel estimation scheme will be further enhanced to have various filter lengths for each multipath component of every CoMP measurement set member

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THANK YOU !

QUESTIONS ?