Coordinated Multi-Point Transmission Aided Cell Switch Off Schemes for Energy Efficient Mobile Cellular Networks

MASc Thesis Defence

By

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Thesis Problem Statement and Motivation

Increasing energy consumption of cellular access networks and Green Radio

- Increased use of cellular devices ⟶ Power consumption burden on cellular networks
- Information and Communications Technology ⟶ 2-10% of global energy consumption
- Access stratum ⟶ 60-80% the whole cellular network energy consumption
- **Optimal Green Radio: Concurrent improvements for energy efficiency and system capacity**

Coordinated Multi-Point (CoMP) transmission technology:

- Key feature of LTE-Advanced standard to mitigate inter cell interference
- Coordination among different transmission points to improve cell edge data rates
- **Potential candidate to deliver green radio solutions by decreasing the energy cost per bit**

Thesis Goals:

- Analysis of CoMP performance in terms of energy efficiency and capacity
- Investigate joint use of CoMP with existing energy efficient cell switch off schemes
- Identify and tackle technical challenges and performance bottlenecks of CoMP schemes
- Create a framework for time-varying downlink CoMP joint transmission scheme
- Develop CoMP adaptive channel estimation and prediction schemes to tackle possible system delays and multi-point channel estimation errors

Thesis Contributions

- System delays and channel estimation errors → Joint transmission clustering accuracy → CoMP performance

- Characterized performance degradation sensitivities of various user locations for different mobility conditions
  - Accuracy of joint transmission set clustering → CoMP access network energy efficiency & DL Capacity
  - Users with higher CoMP cluster degrees are more dependent on accurate clustering decisions

- Novel CoMP adaptive multi-point channel estimation filter designs
  - Improved CoMP clustering accuracy and reduced multi-point channel estimation computation complexity
  - Enlarged estimation filters for points that are more likely to take active role in joint PDSCH transmission
  - Various estimation filter lengths for each point in the CoMP measurement set

- Novel multi-point channel feedback reporting method
  - Selective multi-point CSI feedback → Reduced CSI processing time → Accurate clustering decisions
  - Reduced uplink payload

- Threshold-based clustering decisions to balance CoMP capacity versus energy efficiency trade-off

- Comparison of superimposed versus decomposed channel impulse response tracking for CoMP systems

- Downlink CoMP is used by the active cells to serve the users located in the switched off cell

Thesis Outline

- Chapter 2: Overview on Cell Switch Off Methods and CoMP Enhancements
- Chapter 3: Coordinated Multi-Point Aided Cell Switch Off Schemes
- Chapter 4: Performance Analysis of Joint Transmission Scheme Subject to Imperfect CSI Feedback
- Chapter 5: Multi-Point Statistical Channel Estimation and Prediction Schemes
- Chapter 6: Conclusion and Future Work

Green Radio Survey

Innovations for “green radio” are pioneered by EARTH and C2POWER projects:

- Cognitive and cooperative radio to decrease the CO_2 emission by the ICT
- Energy efficient network deployment and resource management schemes

Enabling Methods for Green Radio	
Component Level	Power amplifier efficiency, inactive component deactivation
Link Level	DRX/DTX, reduced signalling, air interface strategies
Network Level	Hierarchical network deployment, macro, micro, pico and femto cells

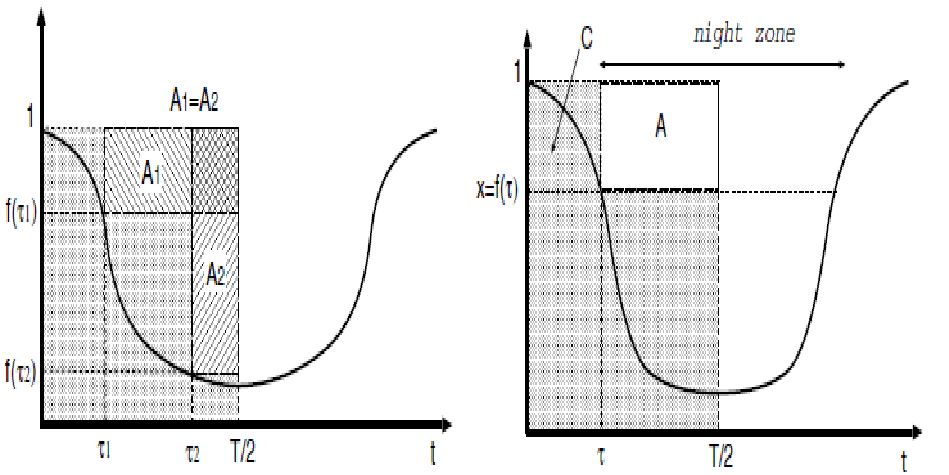
Cell switch off scheme: Most promising candidate for energy savings in cellular networks

- Holistic approach: Combine component, link and network level methods
- Cell with the low traffic conditions is switched off completely
- Component level power saving is maximized
- Coordination among active network nodes

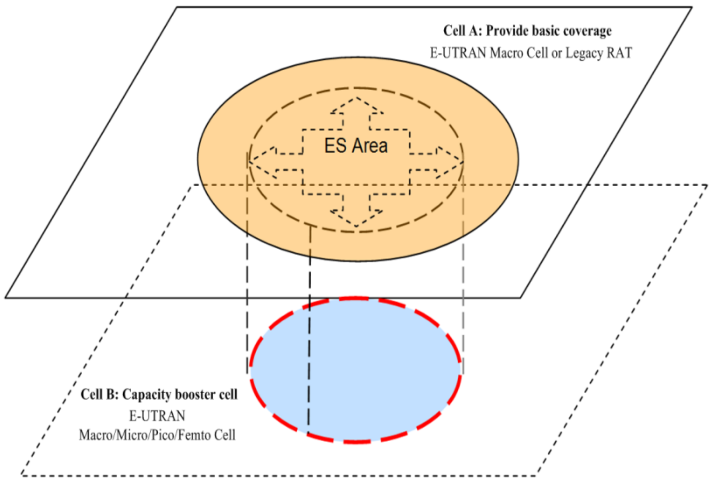
Discussion of Existing Cell Switch-Off Techniques

- Cell size adjustments according to traffic load fluctuations
  - Cells with the low traffic zoom into zero, and the neighbor cells zoom out by physical adjustments
  - Base stations with low Spectral Efficiency are turned off – Spectrally efficient BSs serve the users
  - 24- hour traffic routine is analyzed, optimum cell switch off/on periods are found
  - Ratio between the dynamic and the fixed power of a base station: Switch Off decision parameter

Cell Switch Off Suggestion by Academia:

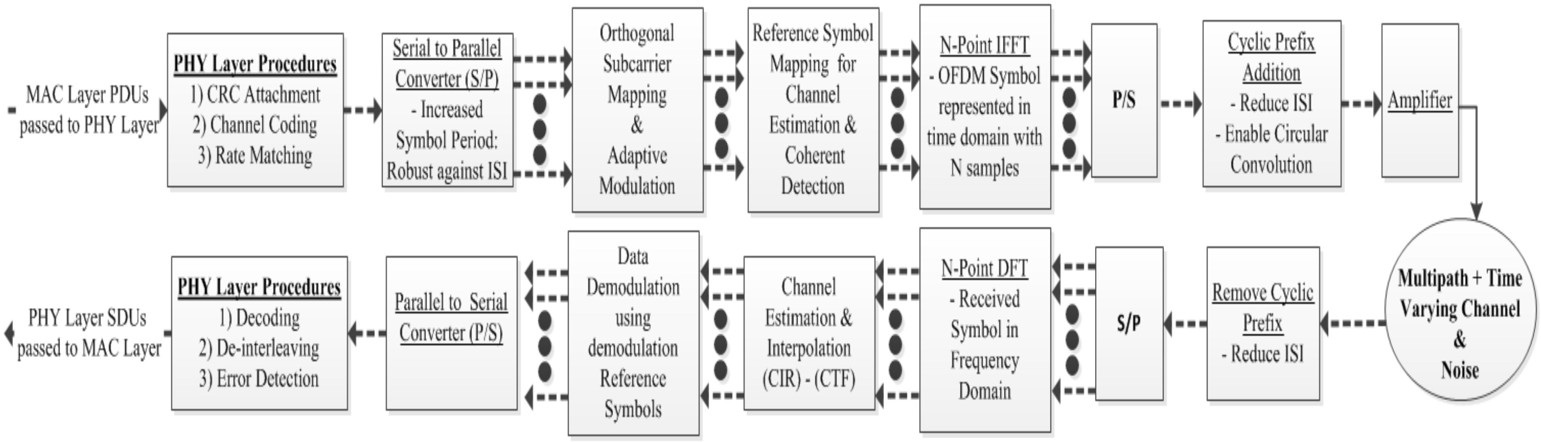


3GPP - Small Cell Switch Off Scheme:



Proposal: Replace antenna tilt/Transmit power increase of active cells by DL CoMP to serve the users in the switched off cell via multiple simultaneous radio links.

Introduction to Downlink LTE Transmission



- ❑ Transmitted signal in time domain after N-IFFT block:

$$x(t) = \sum_{n=-\frac{N_{FFT}}{2}}^{\frac{N_{FFT}}{2}-1} I_{n(t)} \sin\left(2\pi t\left(f_{-\frac{N_{FFT}}{2}} + \Delta f\left(n + \frac{N_{FFT}}{2}\right)\right)\right) - j\, Q_{n(t)} \cos\left(2\pi t\left(f_{-\frac{N_{FFT}}{2}} + \Delta f\left(n + \frac{N_{FFT}}{2}\right)\right)\right)$$

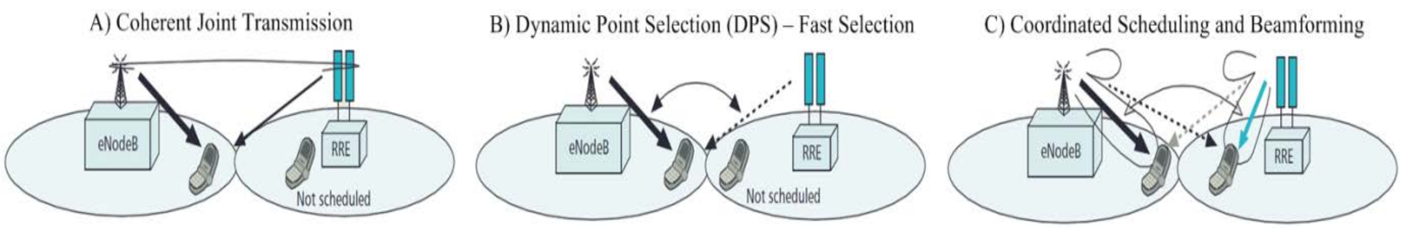
- ❑ Received OFDM symbol after cyclic prefix removal:

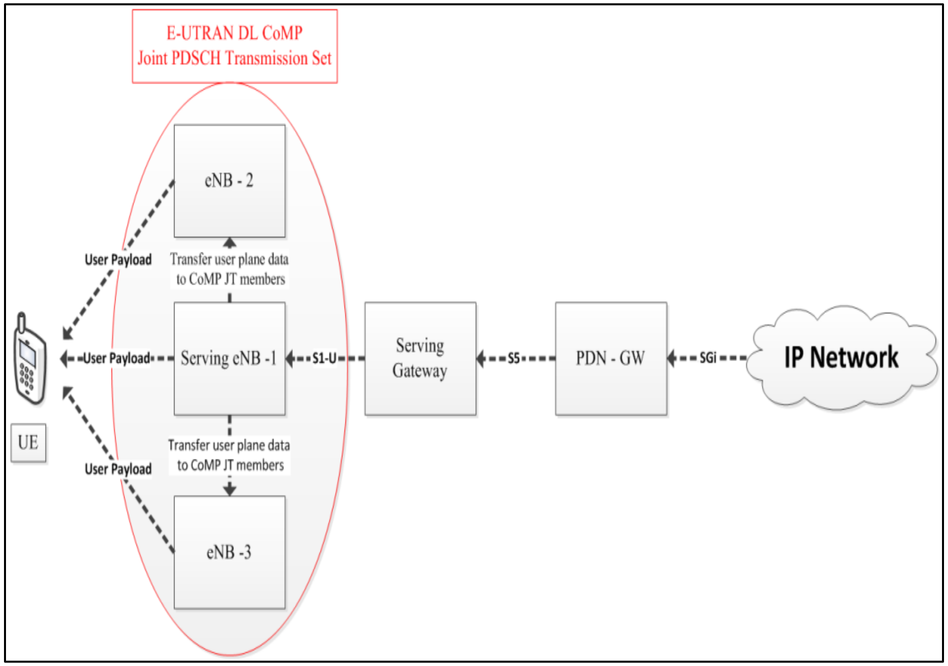
$$y_{Nx1} = F_{NxN}{}^{H} X_{NxN} F_{NxN} h_{Nx1} + n_{Nx1}$$

$$\begin{bmatrix} y_1(k) \\ \vdots \\ y_N(k) \end{bmatrix} = \begin{bmatrix} x_1(k) & x_N(k) & \cdots & x_2(k) \\ \vdots & \vdots & \vdots & \vdots \\ x_N(k) & x_{N-1}(k) & \cdots & x_1(k) \end{bmatrix} \begin{bmatrix} h_1(k) \\ \vdots \\ h_N(k) \end{bmatrix} + \begin{bmatrix} n_1(k) \\ \vdots \\ n_N(k) \end{bmatrix}$$

CoMP Definitions and Standardization

CoMP Definition: Dynamic coordination among multiple geographically separated points referred as CoMP cooperating set for downlink transmission and uplink reception [3GPP 36.819]





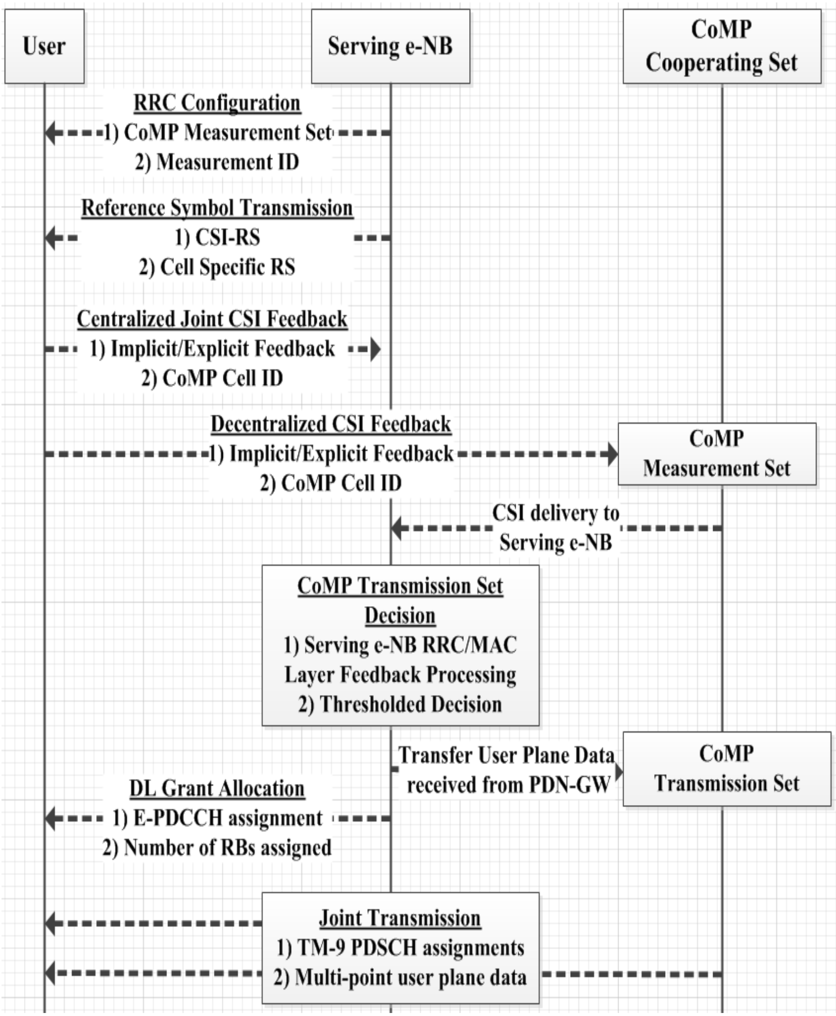
Downlink CoMP Schemes:

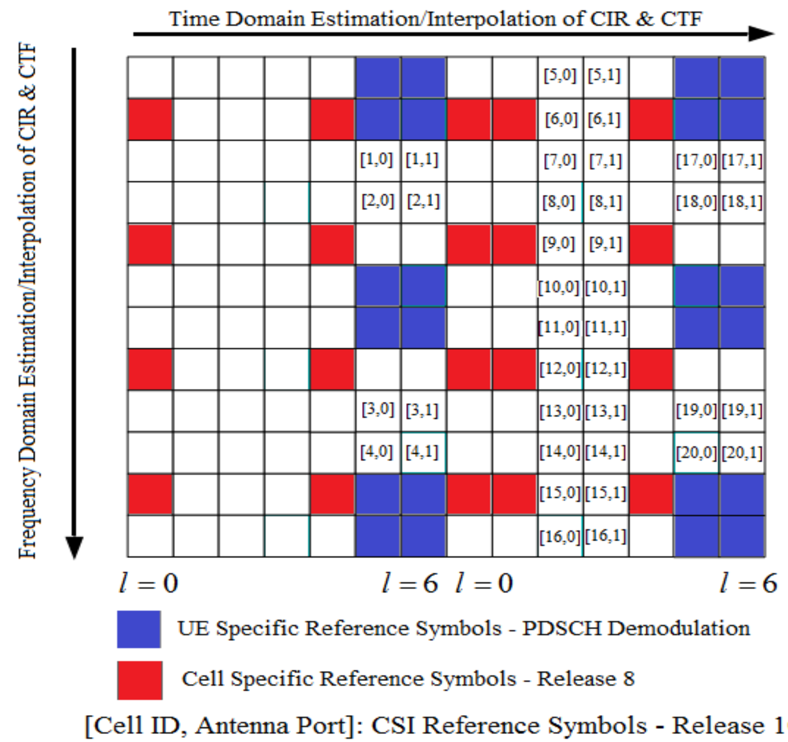
- Joint Processing: User plane data available at each Transmission Point
- Coordinated Scheduling and Beamforming: User plane data available at serving cell

CoMP Deployment Scenarios:

- eNB - eNB
- RRH - RRH
- eNB – High Power RRH
- eNB – Low Power RRH

Joint Transmission Procedures and Multi-Point Channel Estimation





- 3GPP Release-8 devices use CRS for channel estimation (8 REs over RB pair)
- Release-11 CoMP channel estimation depends on CSI-RS (1 RE over RB pair per antenna port for each point)

CoMP Downlink Capacity Performance Metric

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

Single Point Transmission

$$SINR_{pre-LTE-A} = \frac{P_{RX}(n=j)}{\sum_{\substack{n \in N \\ n \neq j}} P_{RX}(n) + P_{noise}}$$

CoMP Downlink Transmission

$$SINR_{CoMP-JT} = \frac{P_{JT}}{\sum_{n \in N \setminus N_{JT}} P_{RX}(n) + P_{noise}}$$

- Total received PDSCH power from downlink joint transmission set assuming the UE receiver performs perfect phase adjustment of sinusoidal crests:

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

- Downlink capacity perceived in bits/sec at each user location *i:*

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

CoMP Energy Efficiency Performance Metric

- Improved spectral efficiency versus increased power consumption trade-off
- Signal processing and backhauling power: Quadratic functions of the CoMP cluster set degree N_C

CoMP Power Consumption Model	
Signal Processing Power	$P_{SP-CoMP} = 58\,(0.87 + 0.1N_C + 0.03N_C^2)$ W
Backhauling Power	$P_{BH} = \frac{C_{BH}}{100Mbits/sec} 50$ W
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	$P_{CoMP} = N_s N_{\frac{PA}{sector}} \left(\frac{P_{TX}}{PA_{eff}} + P_{SP} \right)(1 + C_C)(1 + C_{BB}) + P_{BH}$ W

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 = Joint Transmission Cluster Degree p = pilot density q = CSI signalling

T_S = Symbol Period PA_{eff} = Power Amplifier Efficiency

CoMP Energy Efficiency Performance Metric

- Cellular coverage area per power consumption ratio: m^2/W
  - Used by green network deployment schemes
  - Standalone metric and ignores user perceived QoS
- Standardized energy efficiency KPI for All-IP-Networks: bits/Joule
  - Energy Efficiency (bits/Joule) = $\dfrac{Capacity\ (\mathrm{bits/sec})}{Power\ Consumption\ (\mathrm{Joules/sec})}$

CoMP Access Network Energy Efficiency	
Joint Transmission CoMP Operation ($N_C \geq 2$)	$EE(i) = \dfrac{C(i)}{P_{CoMP} + (N_{C(i)} - 1)(P_{CoMP} - P_{Base})}$
Single Point Transmission ($N_C = 1$)	$EE(i) = \dfrac{C(i)}{P_{Base}}$

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

Urban Macro (UMa) Propagation Model – Large Scale Pathloss

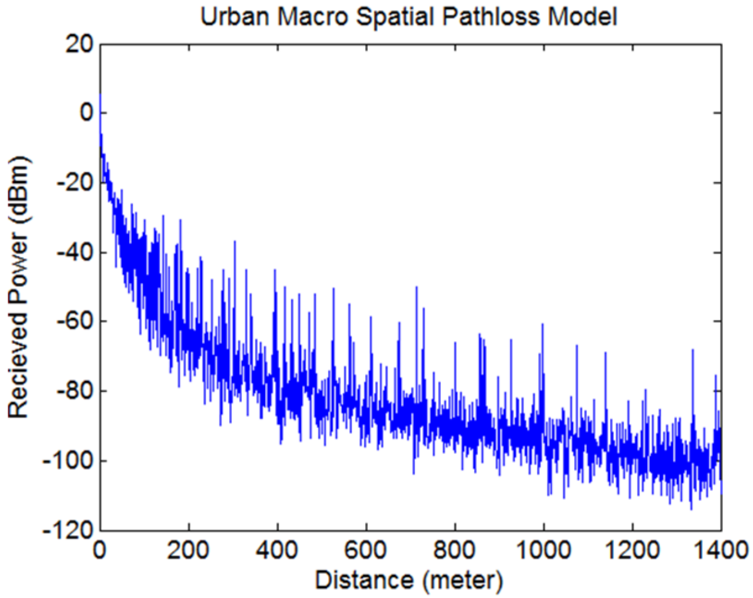
$$PL_{LoS}(dB) = 22\log_{10}d + 28 + 20\log_{10}f_c\ ,\ 10m < d < d_{BP};$$

$$PL_{LoS}(dB) = 40\log_{10}d + 7.8 + 2\log_{10}f_c - 18\log_{10}h_{BS} - log_{10}h_{UT},\ d_{BP} < d < 5000m\ ;$$

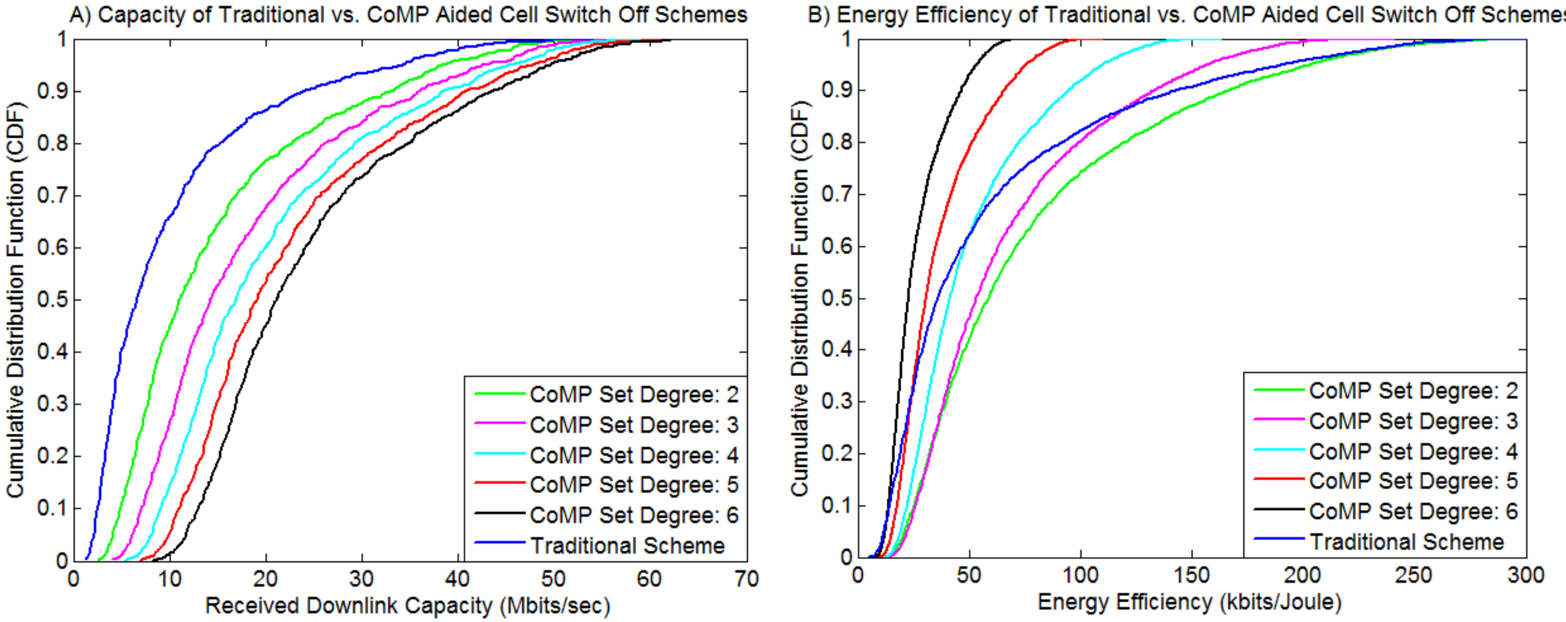
$$PL_{NLoS}(dB) = 161.04 - 7.1\log_{10}L + 7.5\log_{10}h_B - \left(24.37 - 3.7\left(\frac{h}{h_{BS}}\right)^2\right) * \log_{10}h_{BS} + (43.42 - 3.1\log_{10}h_{BS}) * (\log_{10}d - 3) + 20\log_{10}f_c - (3.2(\log_{10}11.75h_{UT}))^2 - 4.97)\ ;$$

$$Prob(LoS) = \min\left(\frac{18}{d}, 1\right) * \left(1 - e^{-\frac{d}{63}}\right) + e^{-\frac{d}{63}}.$$

Parameter	Value
Carrier Frequency (f_c)	2110 Mhz
BS (Base Station) Antenna Height (h_{BS})	24 m
User Terminal Antenna Height (h_{UT})	0.5 m
Average Street Width (L)	20 m
Average Building Height (h_B)	20 m
LoS Shadowing (σ_{LoS})	4 dB
NLoS Shadowing (σ_{NLoS})	6 dB
Break Point Distance (d_{BP})	337.6 m
Transmission Power (P_{TX})	20 W



Traditional Cell Switch Off vs. CoMP Aided Scheme



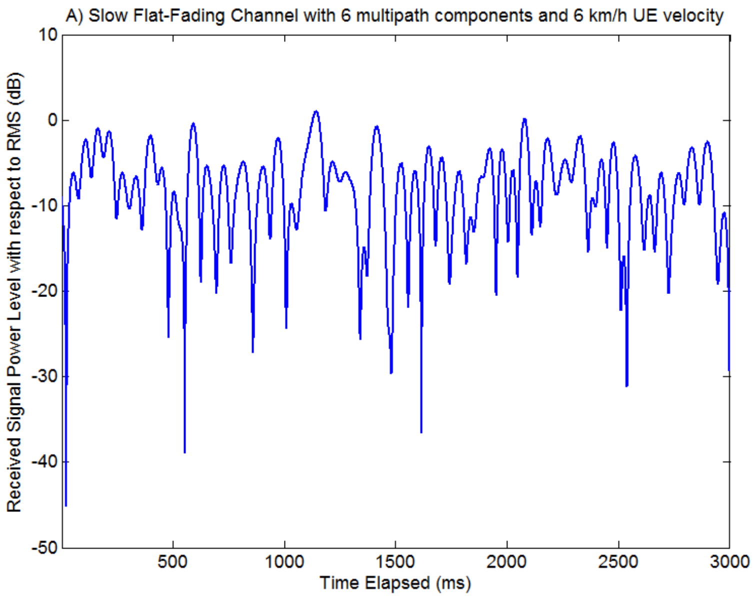
CoMP Joint Transmission Cluster Degree	Mean DL capacity (Mbits/sec)	Mean energy efficiency (kbits/Joule)
$N_c = 1$	9.9737	59.5047
$N_c = 2$	14.7906	78.0615
$N_c = 3$	17.9528	67.2373
$N_c = 4$	20.4614	50.3890
$N_c = 5$	22.6593	36.4919
$N_c = 6$	24.7179	26.6331

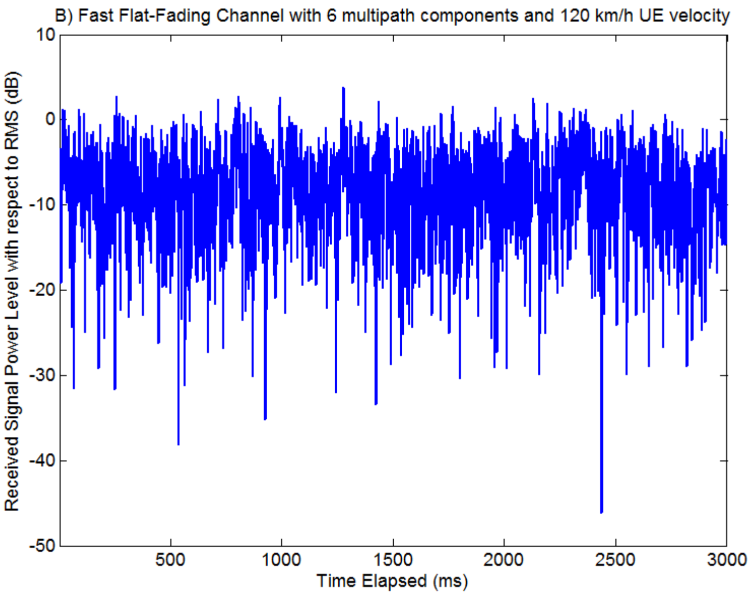
Proof of Concept: Received downlink power adaptive threshold based clustering to balance capacity vs. energy efficiency tradeoff

$$\arg\max_{n}\{P_{RX}(n,i)\} = n_{Best}(i)$$

$$\mathrm{n} \in N_{JT}(i) \quad if \quad |P_{RX}(n_{Best}, i) - P_{RX}(n,i)| \leq \nabla_{NW-JT}$$

Small Scale Fading Model





- Radio channel between UE *i* and CoMP measurement set member $n \in N_{meas}(i,t)$

$$h_{n,i}(t,\tau)=\sum_{l=1}^{L}A_l(t)e^{j2\pi f_{d_l}t}e^{j2\pi f_c\tau_l}e^{j\phi_l}\delta(\tau-\tau_l)$$

- Instantaneous received power fluctuation due to small scale fading

$$P_{Fading}(t)=10\log_{10}\left[\left(\frac{\left|\sum_{l=1}^{L}h(t,\tau_l)\right|}{2}\right)^2\right]$$

CoMP Performance Metrics for Time-varying Channels

Inaccurate multi-point CSI feedback gathered at the serving e-NB

- Multi-point channel estimation errors
  - Transmission through noisy channel
  - Scarce structure of CSI-RS for multi-point channel estimation
- Outdated CSI feedback due to CoMP system delays
  - Network topology constraints
  - Multi-point feedback consolidation and processing procedures
  - Exchange of user plane data for joint PDSCH transmission

- Actual measured received power

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

- Faulty multi-point measurements

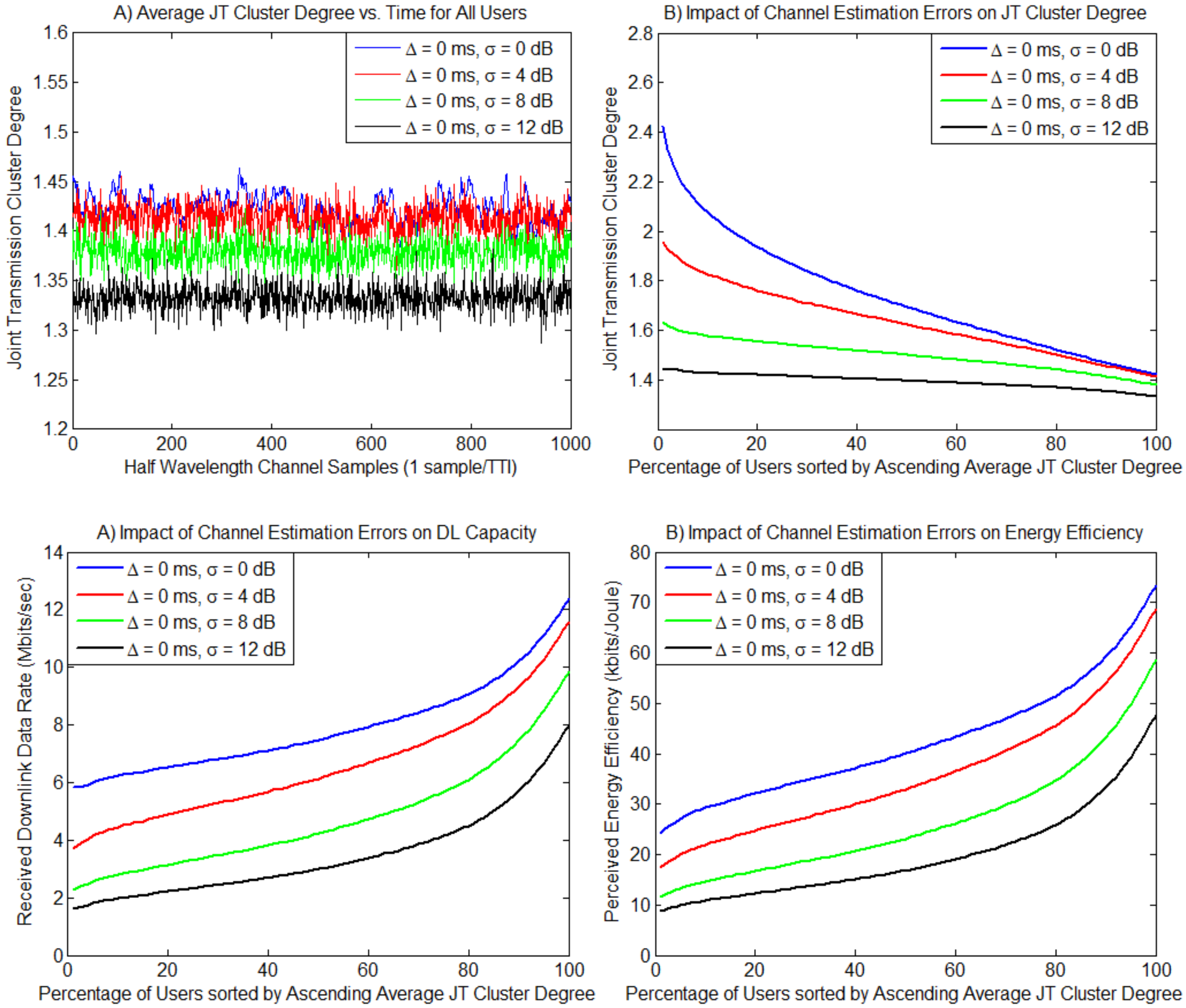
$$P_{RX\_err}(n,t,i) = P_{RX}(n,t-\Delta,i) + P_{err}(\mu,\sigma)$$

- Inaccurate joint transmission clustering decisions

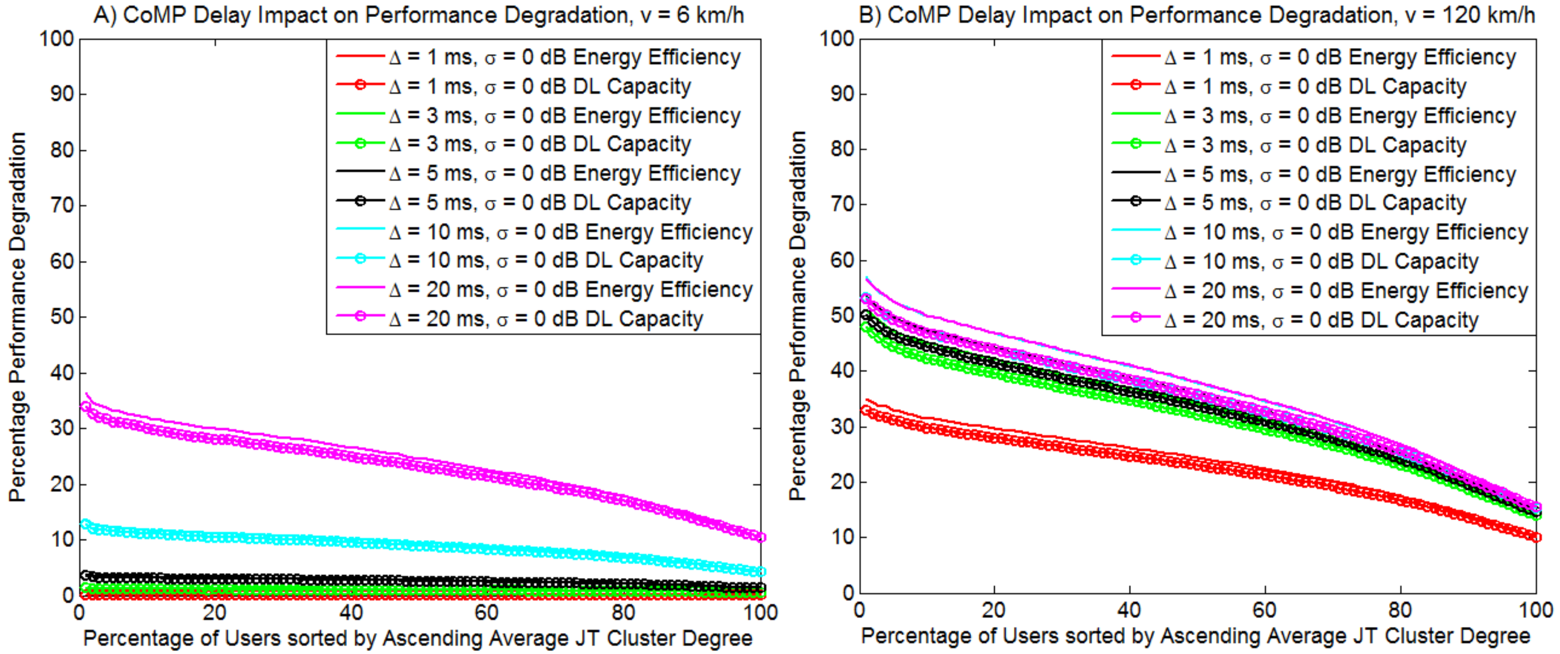
$$\mathrm{n} \in N_{JT}(i,t) \quad if \quad |P_{RX_{err}}(n_{Best},i,t) - P_{RX_{err}}(n,i,t)| \le \nabla_{NW-JT}$$

$$N_C(i,t) = size(N_{JT}(i,t))$$

Performance Degradation due to Multi-Point Channel Estimation Errors



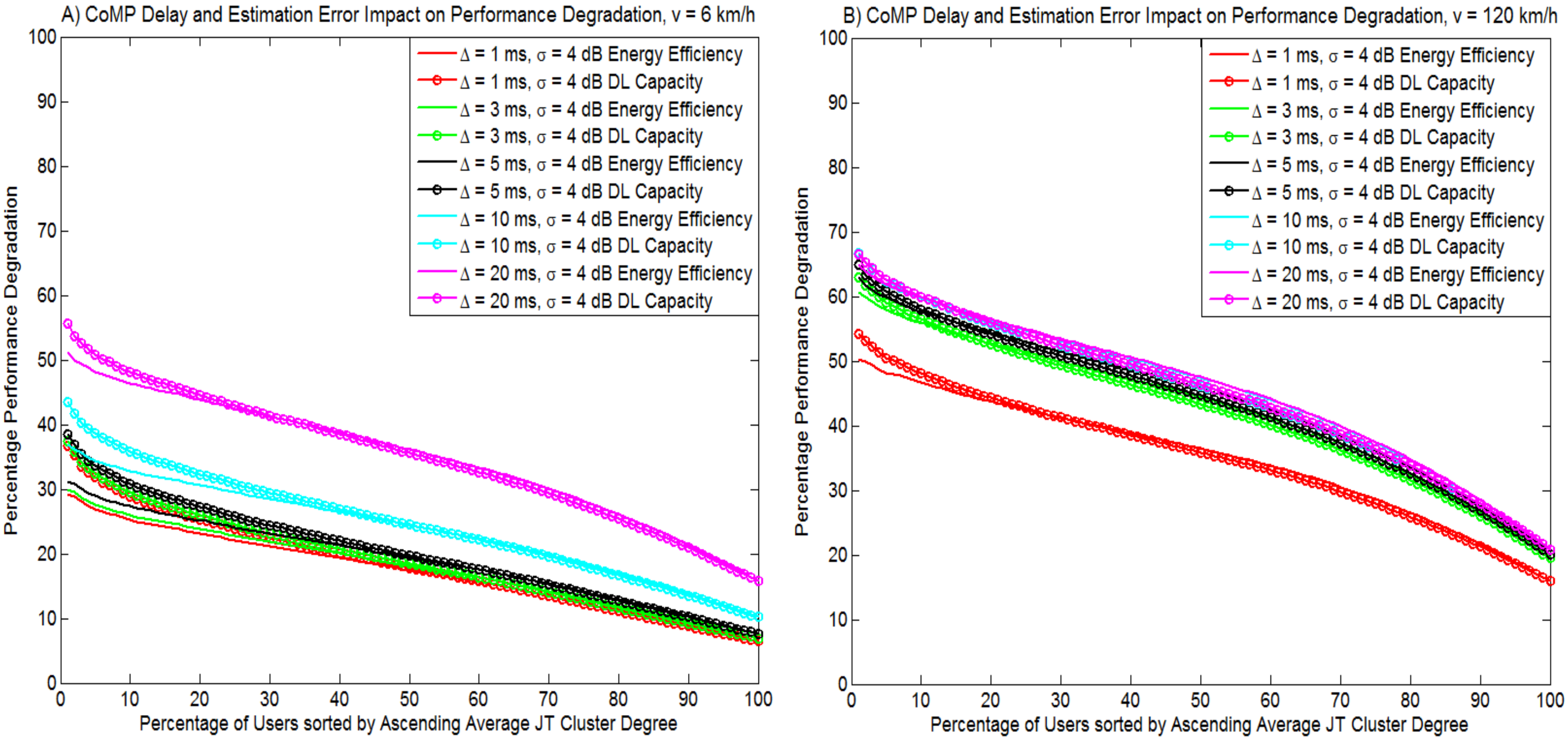
Performance Degradation due to CoMP System Delay



Increased System delay or High Doppler shift $\longrightarrow$ Inaccurate CoMP set clustering

- $\text{Prob}\left(\left|h(t_i,\tau_0) - h(t_j,\tau_0)\right| > \varepsilon\right) \leq 2(R_h(|\Delta t = 0, \Delta\tau = 0|) - R_h(|t_i - t_j, \Delta\tau = 0|))/\varepsilon^2$
- CIR autocorrelation, $R_h(\Delta t, \tau_l)$, has a decreasing nature with a peak at $R_h(0,\tau_l)$
- Coherence time: $\Delta t_c \geq \dfrac{\cos^{-1}[R_h(\Delta t) = c_t]}{2\pi f_{d_{max}}}$

Joint Impact of CoMP System Delay and Estimation Errors on Performance



- Users receiving joint PDSCH transmission from larger clusters are more sensitive to CoMP system delays and multi-point channel estimation errors

Time Domain Channel Estimation Schemes

- Auto-regressive MMSE filter to estimate multi-point CIR
  - More recent channel estimates are given higher weights
  - CIR auto-correlation matrix is used to form filter coefficients

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

Decomposed CIR estimation

- $\tilde{h}_{n,i}(t,\tau_l) =$ $[(R_h(\Delta t,\tau_l) + \sigma_{noise}^2 I_{MxM})^{-1} r_h(\Delta t,\tau_l)]^H \hat{\boldsymbol{h}}_{t,\dots t-M+1;\tau_l}$
- $r_h(\Delta t,\tau_l) = \begin{bmatrix} E[h(t,\tau_l)h(t,\tau_l)^*] \\ \vdots \\ E[h(t-M+1,\tau_l)h(t,\tau_l)^*] \end{bmatrix}$
- $\hat{\boldsymbol{h}}_{t_{n,..,n-M+1};\tau_l} = \begin{bmatrix} \hat{h}(t,\tau_l) \\ \vdots \\ \hat{h}(t-M+1,\tau_l) \end{bmatrix}$

Superimposed CIR estimation

- $\tilde{h}_{n,i}(t) =$ $[(R_h(\Delta t) + \sigma_{noise}^2 I_{MxM})^{-1} r_h(\Delta t)]^H \hat{\boldsymbol{h}}_{t,\dots t-M+1}$
- $R_h(\Delta t) = \int_{l=1}^{L} R_h(\Delta t,\tau_l)\, d\tau_l$
- $\hat{\boldsymbol{h}}_{t_{n,..,n-M+1}} =$ $\begin{bmatrix} \hat{h}(t) = \sum_{l=1}^{L} \hat{h}(t,\tau_l) \\ \vdots \\ \hat{h}(t-M+1) = \sum_{l=1}^{L} \hat{h}(t-M+1,\tau_l) \end{bmatrix}$

Multi-Point Channel Prediction Scheme used by Serving e-NB

- Multi-point channel estimation procedures performed by the UE are enough to tackle the channel estimation errors
- Serving e-NB should perform channel prediction procedures using the CIR estimates reported by the UE
- Predict how the multi-point CIRs will change at the time of the joint PDSCH transmission
- Channel impulse response *p* TTIs ahead is predicted by:

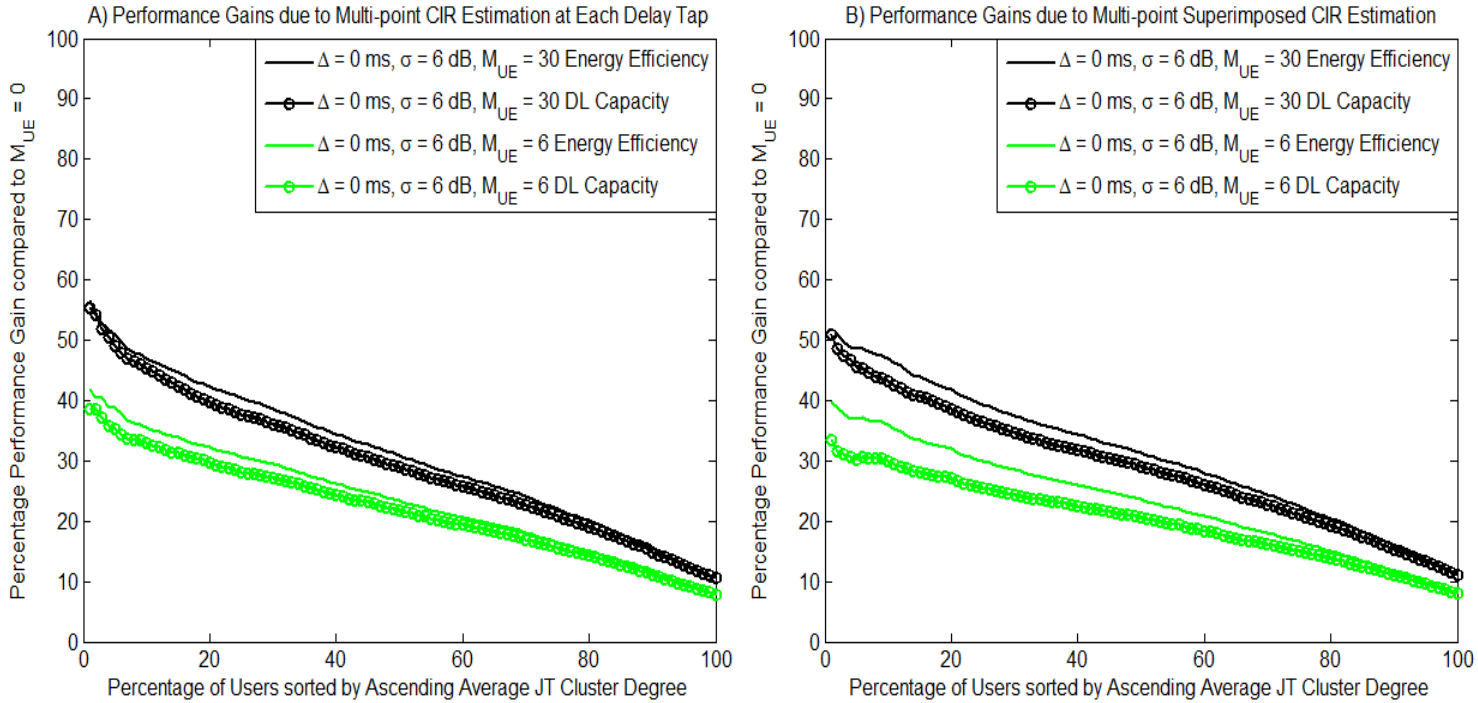
$$\breve{h}_{n,i}(t+p) = \sum_{\substack{m=1\\p>1}}^{p-1} \breve{h}_{n,i}(t+p-m)w(m) + \sum_{m=p}^{M_{NW}} \tilde{h}_{n,i}(t+p-m)w(m) \quad | \quad p \in [1,\ldots,P]$$

- Regularized CIR matrix to generate the filter coefficients are altered as

$$\begin{bmatrix} E[h(t,\tau_l)h(t,\tau_l)^*]+\varepsilon & \cdots & E[h(t,\tau_l)h(t-M+1,\tau_l)^*] \\ \vdots & \ddots & \vdots \\ E[h(t-M+1,\tau_l)h(t,\tau_l)^*] & \cdots & E[h(t-M+1,\tau_l)h(t-M+1,\tau_l)^*]+\varepsilon \end{bmatrix}$$

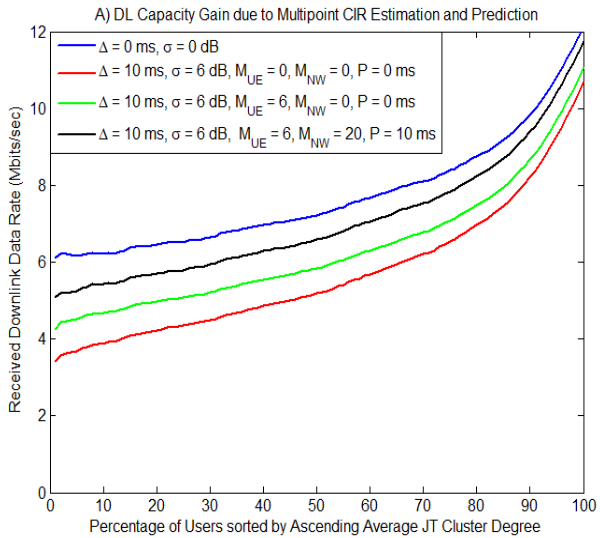
$\tilde{h}_{n,i}$: Estimated CIR sample $\breve{h}_{n,i}$: Predicted CIR sample P: Prediction Range
M_{NW}: CIR Prediction Filter Length M_{UE}: CIR Estimation Filter Length

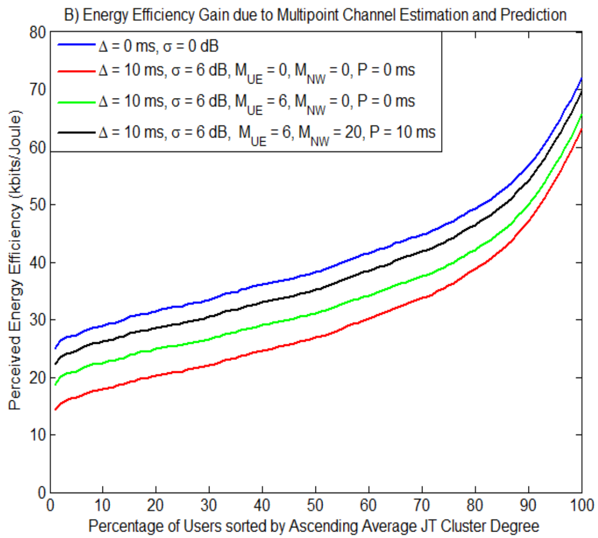
Performance Comparison: Decomposed vs. Superimposed CIR Estimation

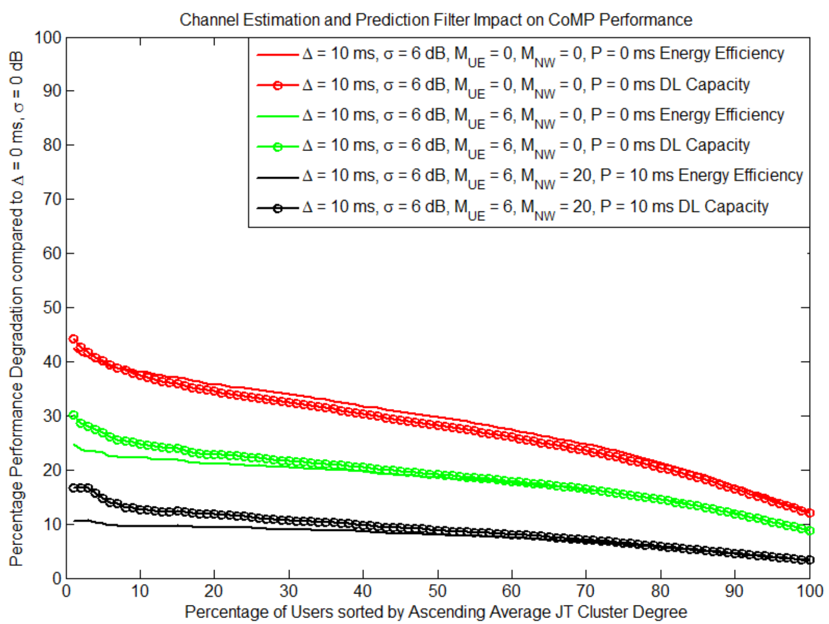


- ❑ Tracking each delay tap ➡ Improved clustering accuracy and CoMP performance
- ❑ Tracking superimposed CIR ➡ Reduced channel estimation computation complexity
- ❑ Increased computation complexity may introduce additional CSI feedback delays
- ❑ UEs may choose to switch between two schemes depending on the computation complexity versus CoMP clustering accuracy trade-off

Performance Gains due to Multi-Point Channel Estimation and Prediction







- Channel prediction range is set equal to the observed CoMP system delay: P = Δ
- Joint use of multi - point channel estimation and prediction schemes tackle the performance degradations caused by inaccurate and outdated CSI feedback

CoMP Adaptive Channel Estimation Filter Design

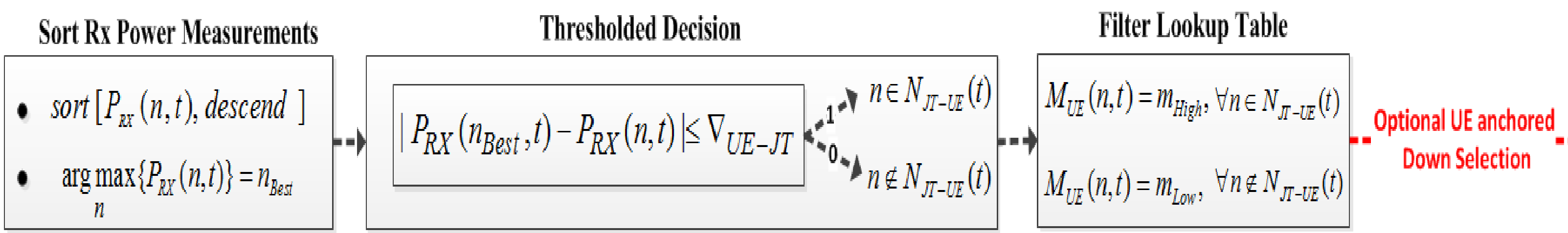
- Multi-point channel estimation filters should be designed according to the UE's CoMP parameters.
- None CoMP adaptive multi-point channel estimation filter length choices cause the below problems:
  - Exclusion of a potential point from the CoMP cluster ➡ Energy Efficiency ⬇ Capacity ⬇
  - Inclusion of an incorrect point in the CoMP cluster ➡ Energy Efficiency ⬇ Capacity ⬆
  - Chanel estimation filter length increases for less CoMP dependent UEs increase the computation complexity of the CIR estimation unnecessarily
  - Using the same CIR estimation filter length for all the channels between the UE and the CoMP measurement set members increases the computation complexity unnecessarily
- Existing channel estimation algorithms adapt channel estimation filter memory spans according to:
  - Receiver velocity , coherence time of the channel and noise variance of the channel

✓ **Proposal:** Adapt the memory span of the multi-point channel estimation filters according to both the current and previously observed time-varying CoMP characteristics of the UE

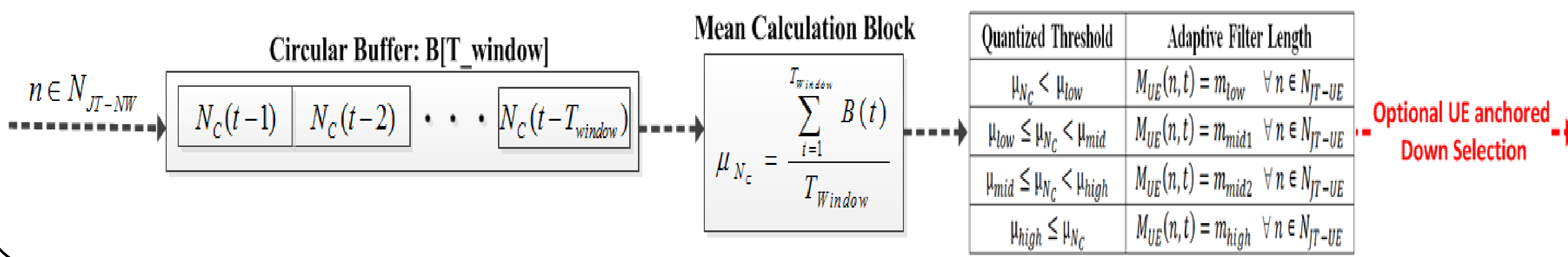
✓ **Goal:** Enlarged filter lengths used by UEs having higher mean clustering degrees only for the points that are likely to take active role during joint PDSCH transmission

CoMP Adaptive Channel Estimation Filter Design

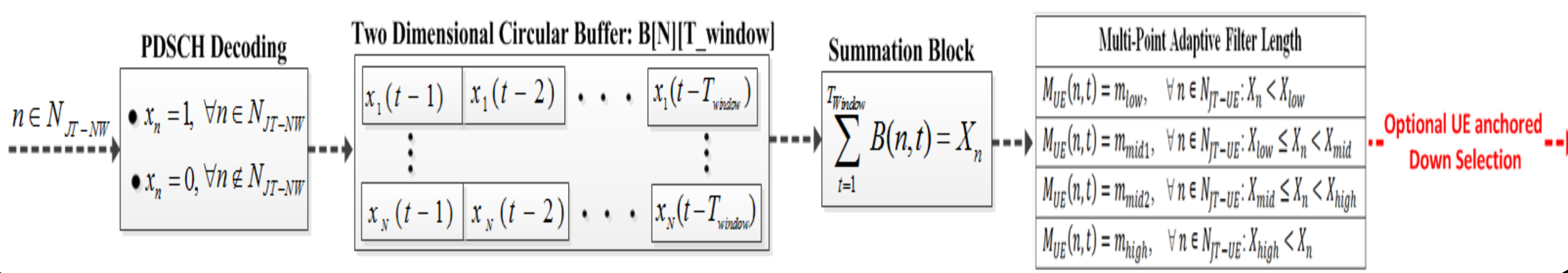
User Driven Instantaneous Received Power Thresholding



Moving Mean of Joint Transmission Cluster Degree



Independent Tracking of CoMP Measurement set points



Adaptive Filter Lookup Table Formation

CIR Auto-correlation	Coherence Time	Filter Length (Memory Span)
c_{high}	$\Delta t\_low_{c_{high}}$	m_{low}
c_{mid}	$\Delta t\_mid_{c_{mid}}$	m_{mid}
c_{low}	$\Delta t\_high_{c_{low}}$	m_{high}

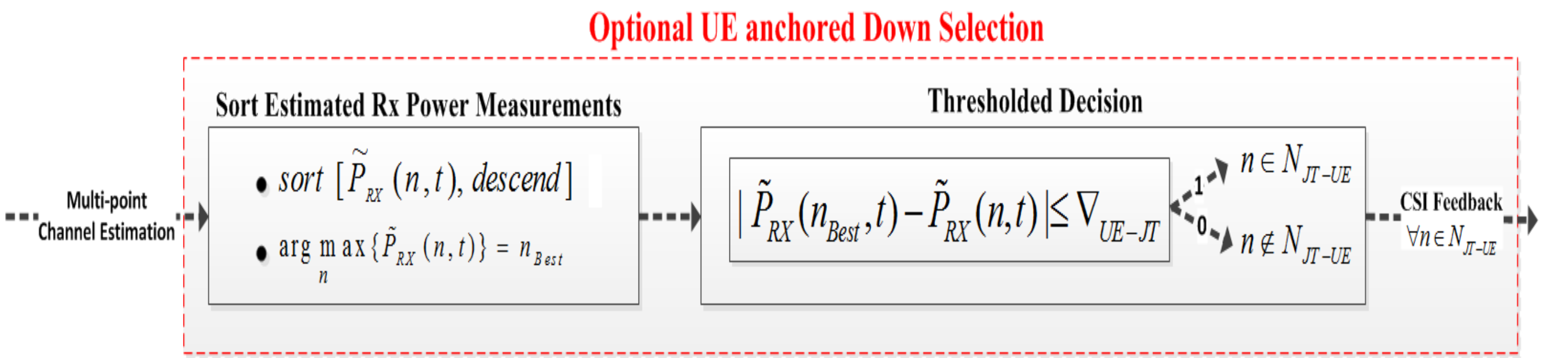
- Adaptive multi-point channel estimation filter lengths:

  $M_{UE} = [m_{low}, m_{mid}, m_{high}]$

- Filter memory span = Number of previous channel samples to store
- Quantized mapping between the CIR autocorrelation value and M_{UE}
- Coherence time between the first and last members of the stored CIR values:
  - $$\Delta t_c = t_1 - t_{M_{UE}} \geq \frac{\lambda cos^{-1}[R_h\left(\Delta t = t_1 - t_{M_{UE}}\right) = c_t]}{2\pi v}$$
- Filter length is found by using the CSI-RS density:
  - $m(n,t) = d(n,t)\Delta t_c$, where $d(n,t) = \frac{\# \, CSI-RS}{TTI}$

UE Anchored Down-Selection for CoMP Joint Transmission Cluster

- ∇_{UE-JT} is the UE defined threshold to predict the members of the joint transmission set after performing channel estimation
- Fine tuning: $\nabla_{UE-JT} = \nabla_{NW-JT} + s\sigma_{P_{err}}$
- UE adapts to various network that have different clustering threshold configurations



<u>Selective Multi-point CSI feedback</u>

- Reduced uplink payload
- Reduced CIR prediction complexity
- Reduced CoMP system delay
- Avoid unnecessary CSI processing
- Faster CSI aggregation
- Accurate clustering decisions
- Decreased processing and clustering decision burden at the serving e-NB

Conclusion

- CoMP aided cell switch off schemes are superior to the traditional cell switch off schemes in terms of both downlink capacity rates and access network energy efficiency
- Threshold-based clustering method makes sure that the energy efficiency of the CoMP access network is not degraded while trying to improve the cell edge data rates
- UEs with higher CoMP set degrees are more sensitive to CSI delays and estimation errors yielding inaccurate clustering decisions at the serving e-NB
- Tracking the decomposed CIR at each multipath delay tap yields more accurate CIR estimates but comes along with increased computation complexity
- LTE-A serving e-NBs address the discrepancies caused by outdated CSI feedbacks by performing CIR prediction for each $UE - n \in N_{meas}$ link before forming the joint transmission clusters
- UEs subject to PDSCH transmission from smaller clusters can decrease the auto-regressive filter lengths to avoid the computation complexity overhead
- Only the points that are more likely to be included in the joint transmission sets are estimated with larger filters
- Processing burden on the anchor e-NB is further decreased by the UEs taking initiative on the clustering decisions and sending out CSI feedbacks after performing down-selection

Publications, Patent Filings and Ongoing Work

- **G. Cili**, H. Yanikomeroglu, and F. R. Yu, "Cell switch off technique combined with coordinated multi-point (CoMP) transmission for energy efficiency in beyond-LTE cellular networks," in *Proc. IEEE ICC'12 Workshops,* Ottawa, ON, Canada, June 2012.

- **G. Cili**, H. Yanikomeroglu, and F. R. Yu, "Energy efficiency and capacity evaluation of LTE-Advanced downlink CoMP schemes subject to channel estimation errors and system delay," submitted to *IEEE ICC'13*, Budapest, Hungary, June 2013.

- **G. Cili**, H. Yanikomeroglu, and F. R. Yu, "CoMP adaptive channel estimation prediction filter design," Filed by Apple Inc., U.S. Patent Application No: 61/674,852 (filing date: July 23, 2012).

- **G. Cili**, H. Yanikomeroglu, and F. R. Yu, "UE anchored down-selection for CoMP joint transmission cluster," Filed by Apple Inc., U.S. Patent Application No: 61/674,854 (filing date: July 24, 2012).

- **G. Cili**, H. Yanikomeroglu, and F. R. Yu, "Coordinated multi-point adaptive channel estimation and prediction schemes for accurate joint transmission clustering," to be submitted to an IEEE journal, Sept. 2012.

Possible Enhancements and Future Work

- **Dual mode operation:** Dynamic switching between the traditional and CoMP aided cell switch off schemes according to the UE distribution and scheduling in the access network
- **More realistic data rate calculations:** Multi-Point CSI feedback versus adaptive modulation and coding (AMC) scheme mapping for LTE - Advanced CoMP systems
- Tracking the time-varying CTF in frequency domain using the time dispersive characteristics of the channel, investigate complexity for various subcarrier assignments
- Replace auto-regressive MMSE filters by more advanced Kalman filters
- Develop multi-path adaptive CoMP channel estimation filters: $M_{UE}(n, t, l)$
- Analyze the effects of CIR estimation computation time on CSI feedback delay
- Investigate energy efficiency and downlink capacity maximizing joint transmission set clustering decisions under dynamic MAC layer scheduling decisions every TTI

THANK YOU!

QUESTIONS ?