Cell Switch Off Technique Combined with Coordinated Multi-Point (CoMP) Transmission for Energy Efficiency in Beyond-LTE Cellular Networks

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Introduction

- Energy Efficiency of Cellular Systems became a major performance metric:
  - Increased use of cellular devices -> CO_2 emission rise in cellular networks
  - Information and Communications Technology is responsible for 2-10% of global energy consumption
  - Access stratum is responsible for 60-80% the whole cellular network energy consumption
  - Energy Efficiency metric: **Bits/Joule** should be jointly considered with spectral efficiency metric

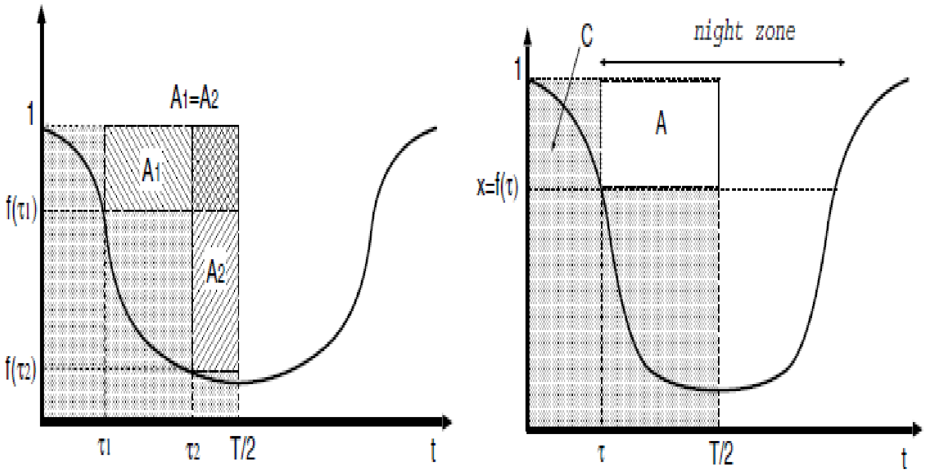
- Methods for Energy Efficient Access Networks:
  - Energy efficiency in Base Stations
  - Energy efficiency using Cooperative Base Station Schemes
  - Energy Efficiency using renewable energy resources
  - Energy efficiency via heterogonous networks
  - Cognitive Radio & Cooperative relaying for Energy Efficiency

- Our contributions
  - LTE-A Downlink CoMP used jointly with traditional Cell Switch Off Schemes
  - Model energy & spectral efficiency of CoMP + Cell Switch Off Schemes
  - Use DL CoMP to serve the users in switched off cell
  - Demonstrate CoMP challenges: Estimation Errors + System Delays

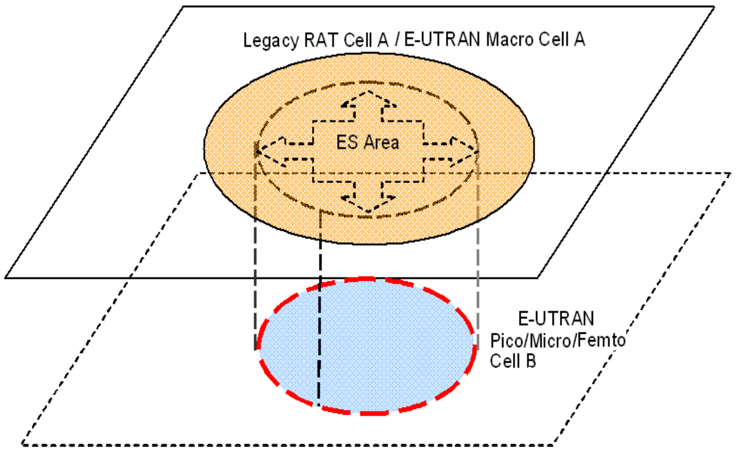
Overview of Green Access Networks

- 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 [6]:

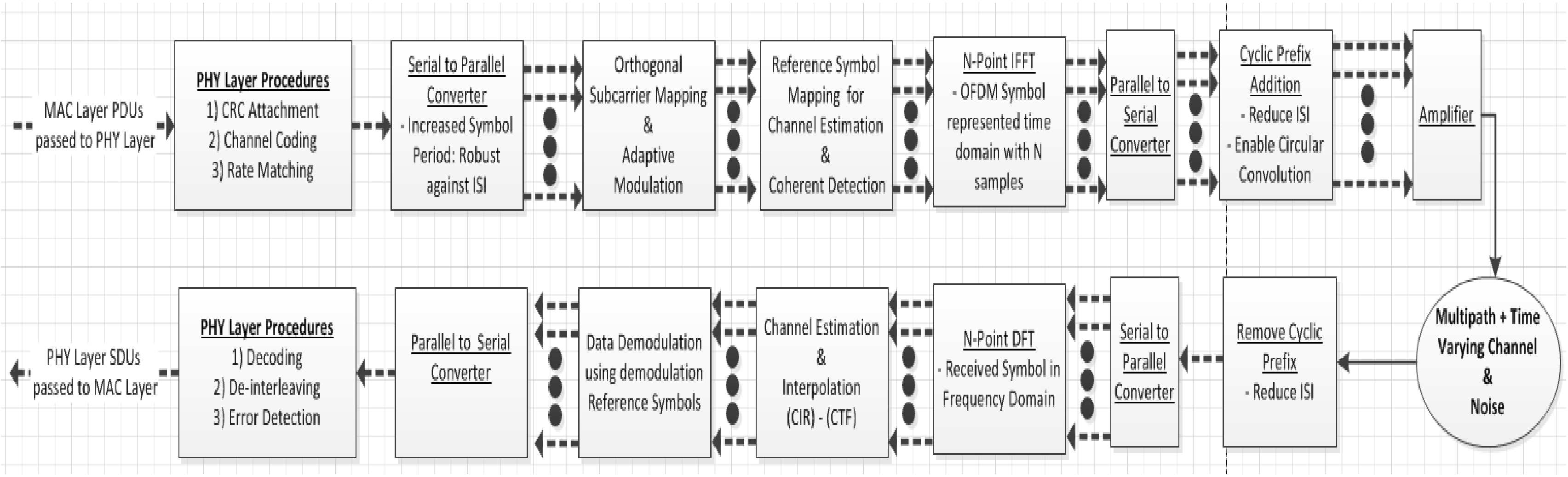


3GPP - Small Cell Switch Off Scheme [15]:



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

LTE Downlink Transmission and CoMP Procedures



$$y_{Nx1} = x_{NxN} h_{Nx1} + n_{Nx1}$$

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

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

LTE Downlink Transmission and CoMP Procedures

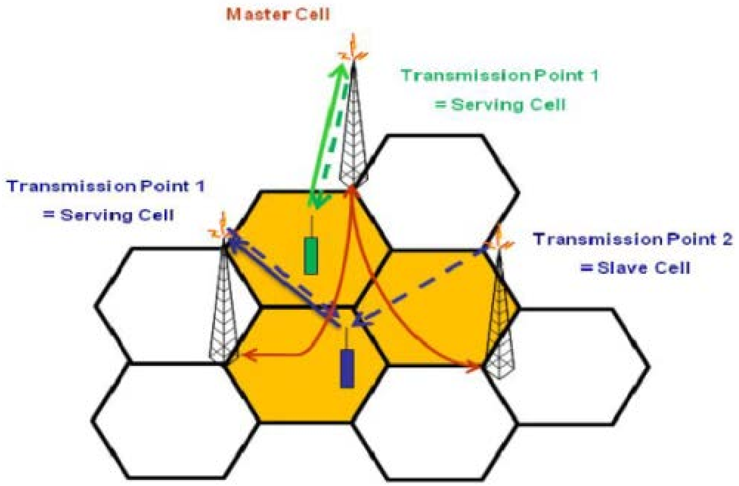
CoMP Definition: Dynamic coordination among multiple geographically separated points referred as CoMP cooperating set for downlink transmission and uplink reception

Downlink CoMP Schemes:

1) Joint Processing: User Plane Data available at each Transmission Point
2) Coordinated Scheduling/Coordinated Beamforming: User Plane Data @ Serving Cell

CoMP Deployment Scenarios:

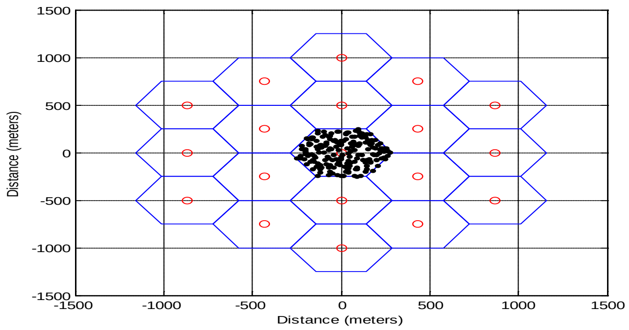
1) eNB - eNB
2) RRH - RRH
3) eNB – High Power RRH
4) eNB – Low Power RRH

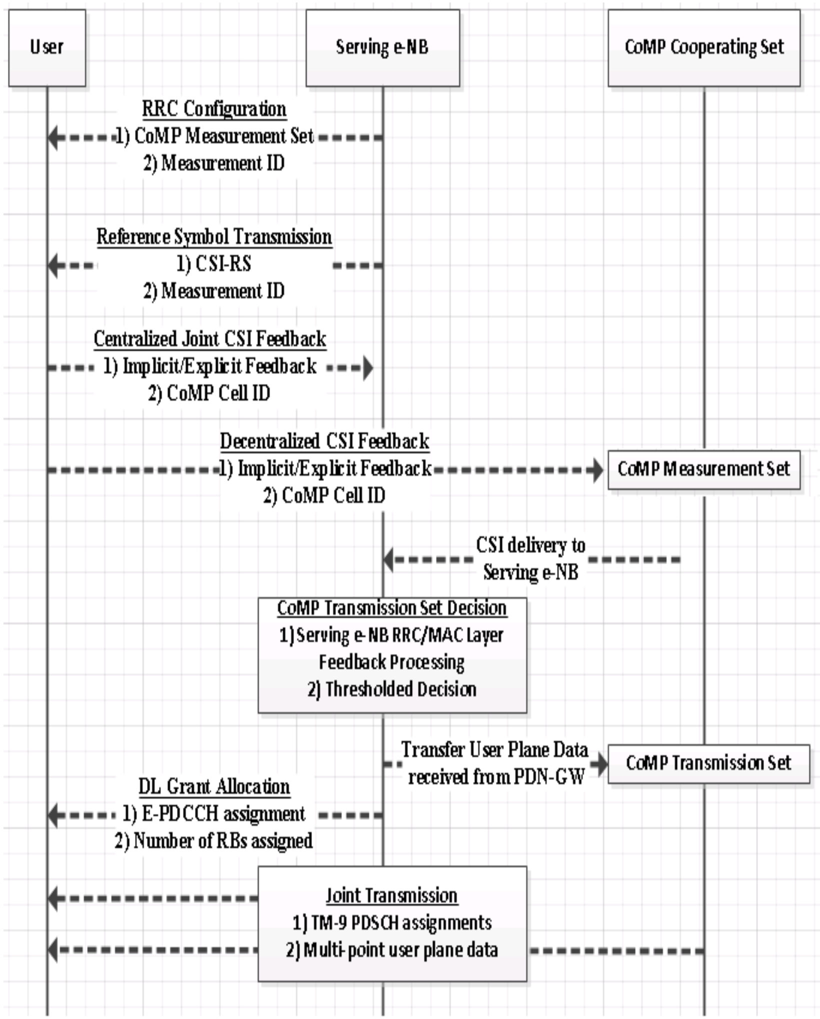


CoMP + Cell Switch Off Model

Cellular Layout + Parameters:

1) 19 eNBs with hexagonal layout
2) Center Cell Switched Off,
3) Remaining 18 eNBs are in CoMP Cooperating & Measurement Set
4) Uniform user distribution in the switched off cell $i \in [1,..,500]$
5) Cooperating Cell IDs: $n \in [1,..,18]$
6) Channel samples every TTI according to Winner SCME model: $t \in [1,..,1000]$
7) Each UE-eNB link is modeled independently
8) Large scale path loss model according to ITU-R report M.2135

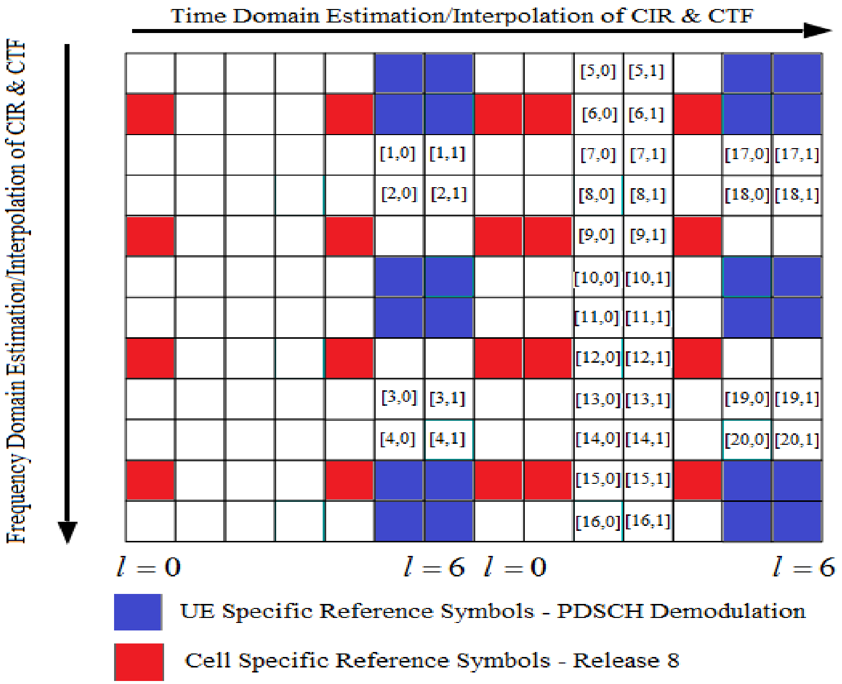




CoMP + Cell Switch Off Model

CoMP Transmission Set Forming:

- Serving cell configures the UE for multi-point measurements for each eNB in CoMP measurement set
- CSI-RS enables Multi-Point Channel Estimation
- Actual measured received power from eNB *n* by user *i* at TTI *t* :
- $P_{RX}(n,t,i) = P_{TX}(n) - PL(n,i) - P_{Fading}(n,i,t)$
- Implicit/Explicit multipoint channel feedback obtained at Serving Cell
- Received feedback due to estimation error + delay:
- $P_{RX\_err}(n,t,i) = P_{RX}(n,t-\Delta,i) + P_{err}(\mu,\sigma)$
- Thresholded Decision to Form the CoMP Transmission Set: Serving Cell Power – Measured cell ≤ 3dB
- Time-varying CoMP Transmission Set: $JT(i,t)$
- Joint PDSCH transmission + Cross-point scheduling over certain time/frequency resources



[Cell ID, Antenna Port]: CSI Reference Symbols - Release 10

Note: Release-8 devices use CRS for channel estimation (8 REs over RB pair), but Rel -11 CoMP channel estimation uses CSI-RS (1 RE over RB pair per antenna port) = Multi-point channel estimation is more vulnerable to channel estimation errors due to scarce REs to track the channel using autocorrelation functions

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

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

Total received Power from CoMP Transmission Set

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

Perceived Downlink Capacity due to CoMP

$$C(i,t) = BW(i,t) * \log_2\left(1 + \frac{P_{JT}(i,t)}{P_{Noise} + \sum_{n\notin JT(i,t)} P_{RX}(n,t,i)}\right)$$

Note: CoMP transmission set $JT(i,t)$ is formed according to delayed and inaccurately estimated channel samples. $BW(i,t)$ is dependent on the number of RBs assigned to UE

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	$C_{BH} = \frac{N_C*(2N_C)*p*q}{T_S}\ bits/sec$
Total Power Consumption of an eNB using CoMP	$P_{\mathrm{CoMP}} = N_s * N_{\frac{PA}{sector}} * \left(\frac{P_{TX}}{PA_{eff}} + P_{SP}\right)(1 + C_C)(1 + C_{BB}) + P_{BH}$

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

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

Time Varying Energy Efficiency	
Joint Transmission CoMP Operation ($N_C \geq 2$)	$EE(i,t) = \frac{C(i,t)}{P_{CoMP} + \left(N_{JT(i,t)} - 1\right) * (P_{CoMP} - P_{Base})}$
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 $N_C = 1$

Propagation Model – Large Scale Pathloss

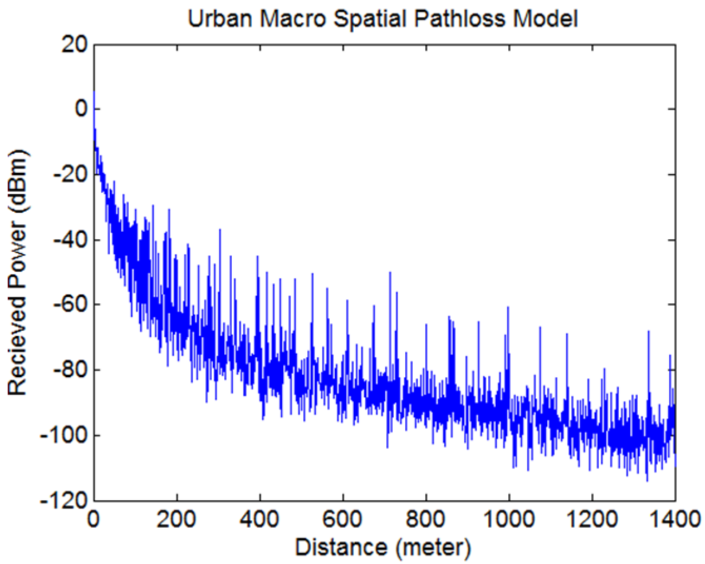
$$PL_{LoS}(dB) = 22\log_{10}d + 28 + 20\log_{10}f_c\,,\ 10m < d < d_{BP};$$

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

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

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

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



Propagation Model – Small Scale Fading

Complex Baseband Channel Impulse Response:

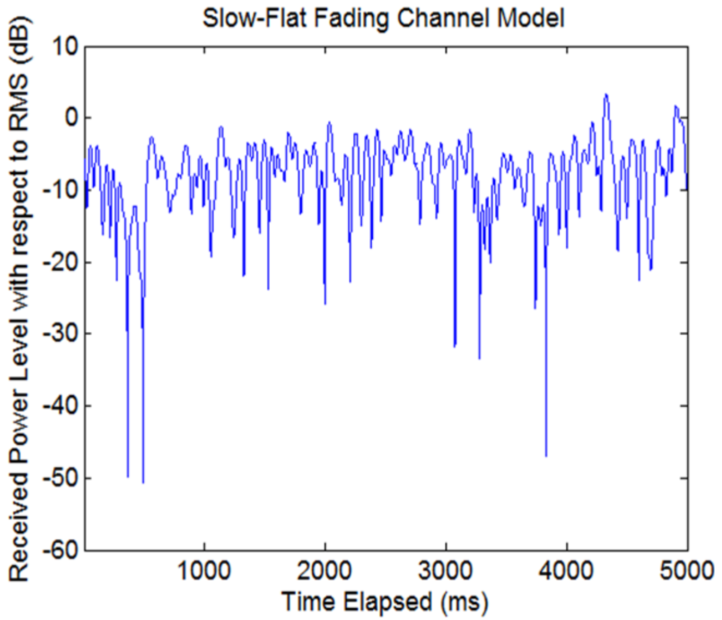
$$h_{n,i}(t,\tau_l) = A_l(t)e^{j2\pi f_{d_l}(t)}e^{j2\pi f_c \tau_l}e^{j2\pi \emptyset_l}\delta(\tau - \tau_l)$$

Received Multipath Signal in Time Domain

$$s(t) = \sum_{l=0}^{L} A_l * \cos(2\pi f_c t + 2\pi f_{d_l} t + \phi_l)$$

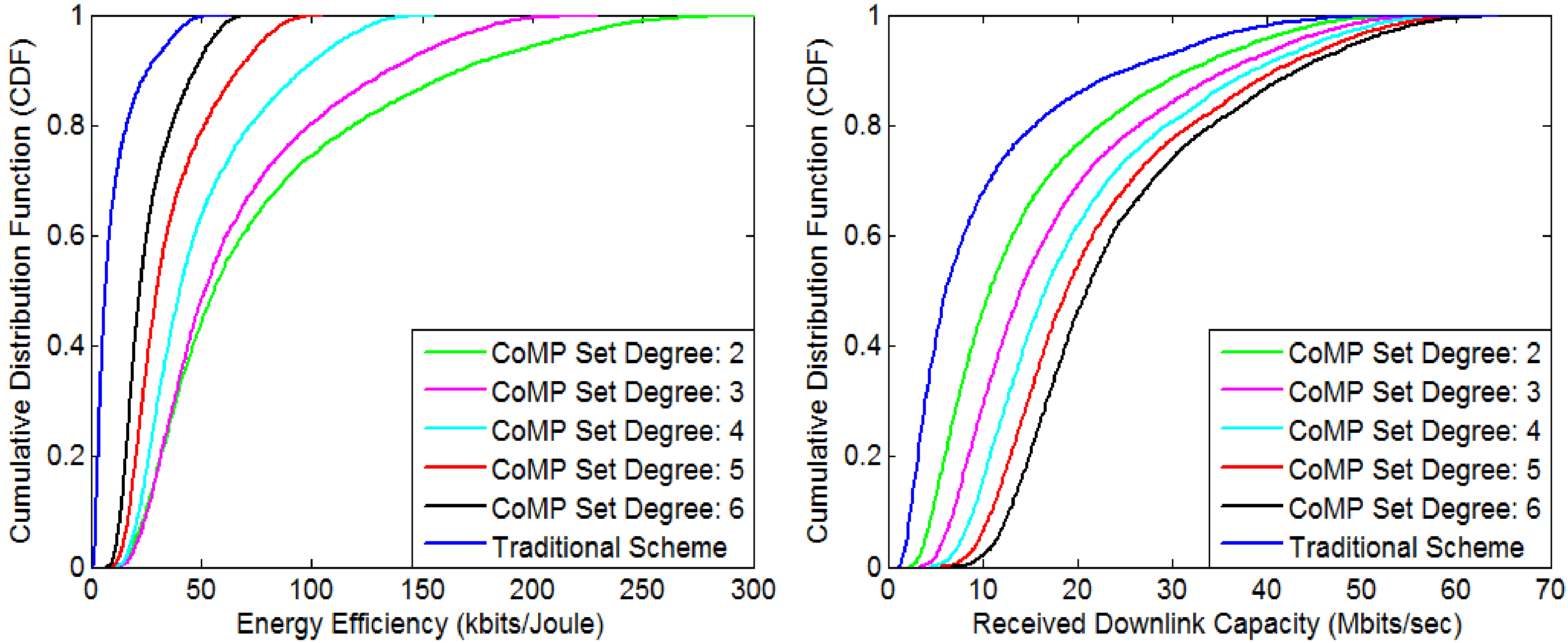
Received Power Change Due to Small Scale Fading

$$P_{Fading}(n,i,t) = 10 * \log_{10}[(\frac{|\sum_{l=1}^{L} h_{n,i}(t,\tau)|}{2})^2]$$



- Complex multipath components go through summation due to the narrow band nature of OFDMA
- Each UE-CoMP measurement set member have independent channels
- Main contributors to the multipath phase are f_{d_l} and $\emptyset_l$; $2\pi f_c \tau_l$ is due to difference of propagation of each multipath delay tap

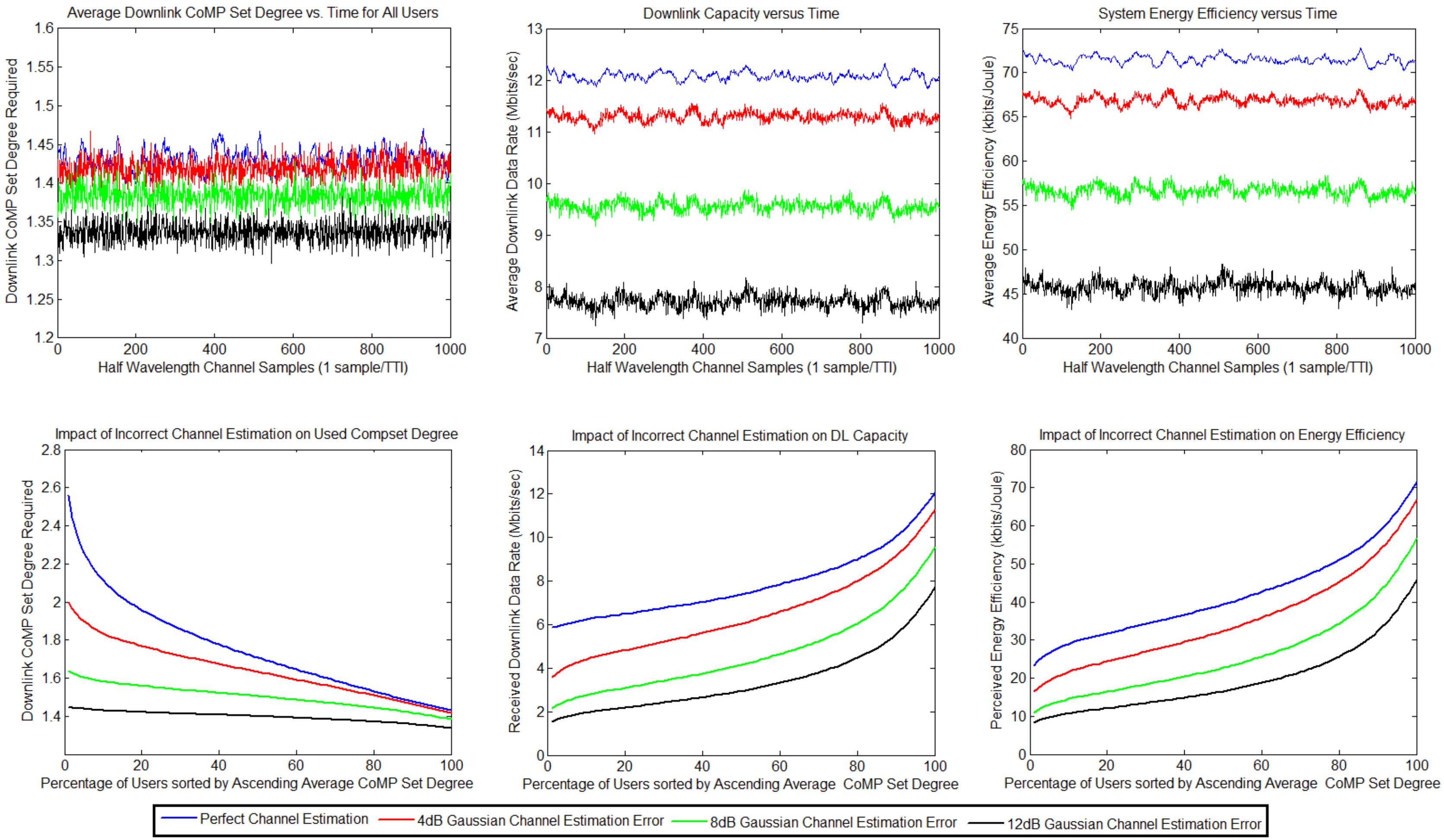
Traditional Cell Switch Off vs. CoMP Aided Scheme



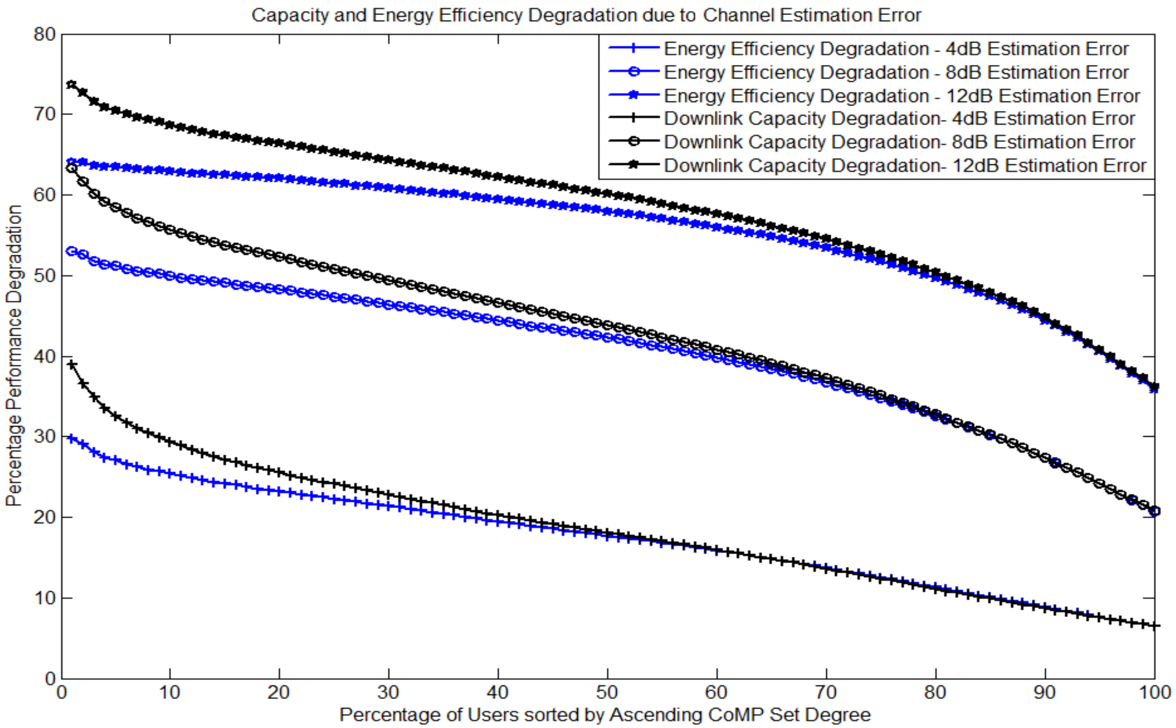
- CoMP aided schemes yield both spectrally and energy efficient systems compared to traditional cell switch off schemes
- Increased CoMP Transmission Set Degree improves the DL capacity due to mitigated ICI
- Non-adaptive increase in CoMP set degree decreases the energy efficiency of the system since the gained capacity is not worth the power consumption overhead
- **Proof of Concept:** *Serving cell needs an adaptive thresholded decision mechanism for Joint PDSCH transmission set clustering.*

Performance Analysis of CoMP Schemes subject to Inaccurate Clustering

Performance Subject to Multi-Point Channel Estimation Errors



Performance Degradation Due to Multi-Point Channel Estimation Errors



- $P_{RX\_err}(n,t,i) = P_{RX}(n,t-\Delta,i) + P_{err}(\mu,\sigma)$
- Users that require higher Joint Transmission CoMP sets get affected the most
- Channel Estimation Errors decrease the used CoMP set degree, eNBs that are supposed to be part of joint transmission get down-selected due to estimation errors
- Energy Efficiency and Capacity get affected differently since Capacity degradation is dependent on CoMP set degree and the choice of points however energy efficiency is reliant on capacity/power trade-off where power consumption is purely dependent on the set degree

Performance Degradation Due to CoMP System Delay

<u>CoMP Clustering Decision Delay are due to:</u>

1) Exchange of multi-point CSI feedback between the CoMP measurement set members and the serving cell (anchor) – lack of aggregate feedback
2) Network Topology Limitations causing latency
3) Node Processing & Decision Delay:
    - Received Power Estimation
    - Sorting the members of CoMP measurement set
    - Thresholded Decision
4) Exchange of User Plane payload between the transmission points

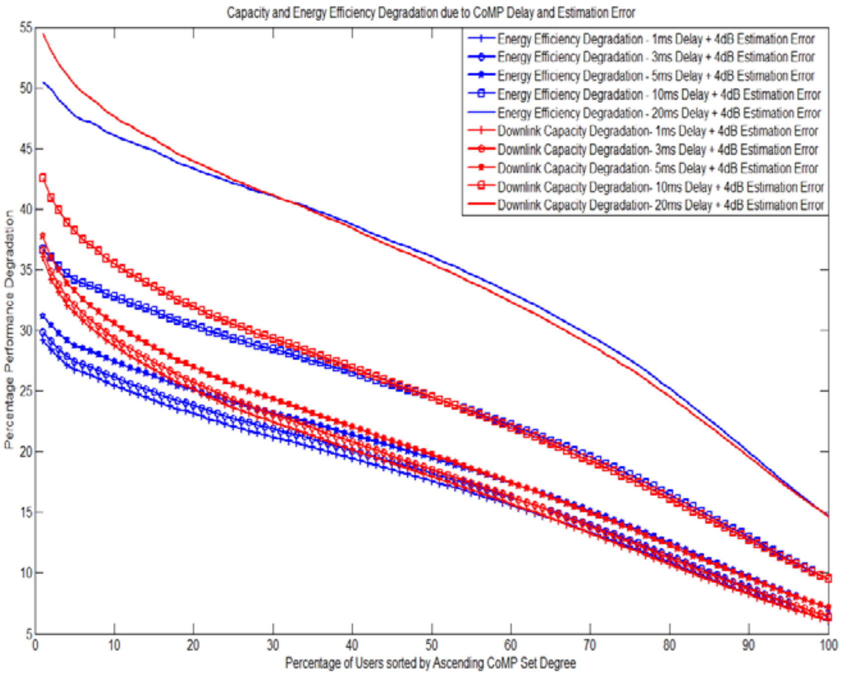
- $R_h(\Delta\boldsymbol{\tau_M}, \tau_l) = \begin{bmatrix} E[h(t_1,\tau_l)h(t_1,\tau_l)^*] & \cdots & E[h(t_1,\tau_l)h(t_N,\tau_l)^*] \\ \vdots & \ddots & \vdots \\ E[h(t_N,\tau_l)h(t_1,\tau_l)^*] & \cdots & E[h(t_N,\tau_l)h(t_N,\tau_l)^*] \end{bmatrix}$

- $Prob\left(\left|h(t_i,\tau_0) - h\left(t_j,\tau_0\right)\right| > \varepsilon\right) \leq 2(R_h(|\Delta t = 0, \Delta\tau = 0|) - R_h\left(\left|t_i - t_j, \Delta\tau = 0\right|\right))/\varepsilon^2$
    - $R_h(\Delta\boldsymbol{\tau_M}, \tau_l)$ is a decreasing function with a maximum value at $R_h(0, \tau_l)$

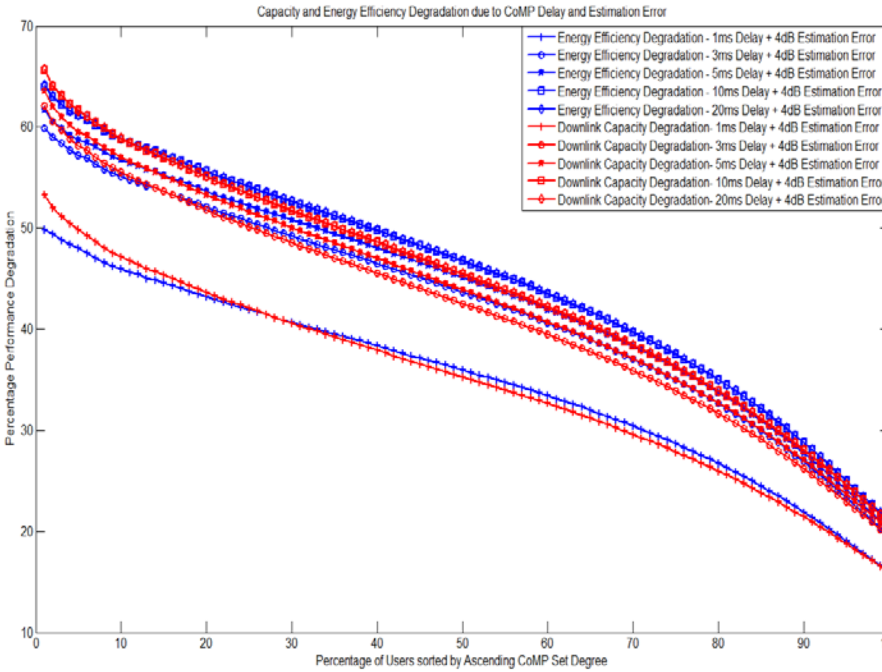
- Increased System delay or High Doppler shift will yield inaccurate clustering

Performance Degradation Due to CoMP System Delay

Performance degradation under low mobility conditions $(v = 6km/h)$



Performance degradation under high mobility conditions $(v = 120km/h)$



- For low coherence time scenarios, CoMP clustering gets affected severely
- Multi-point channel estimation errors had a direct impact on decreasing the used joint transmission set degree, whereas system delays create performance degradation just by changing the members of the CoMP set for the same set degree

CONCLUSION & SUMMARY

- CoMP aided cell switch off schemes yield both energy and spectra efficient systems
- Unneccessary increase CoMP set degree decreases the energy efficiency of the system
- Capacity/Power trade-off for the CoMP systems are achieved by Serving cell thresholding decision for joint PDSCH transmission set clustering
- Traditional Cell switch off schemes have the challenge of proper traffic routine modeling
- CoMP aided Cell Switch Off schemes are dependent on CSI feedback & clustering decision accuracy
- Multi-point channel estimation errors degrade the performance by decreasing the overall average CoMP set degree
- CoMP system delays degrade the performance by inaccurate choice of transmission set points while keeping the set degree same
- Inter-eNB deployment scenario suffers from faulty clustering under High Doppler conditions

Future Work

- Time-varying nature of each multipath delay for each point mentioned in CoMP measurement set should be tracked individually using estimation/interpolation filter for CIR
- Tracking will be dependent on multi-point channel estimation each TTI and interpolation of the results over various subframes
- **Estimation Filter length M should be adapted according to the CoMP set degree observed, especially for low mobility cases that has high CoMP set degrees increased filter length will improve the performance significantly**

- $\tilde{h}_{t_n,\tau_l} = [(R_h(\Delta t,\tau_l) + \sigma_{noise}^2 I_{MxM})^{-1} r_h(\Delta t,\tau_l)]^H \hat{\boldsymbol{h}}_{t_{n,..,n-M+1};\tau_l}$

- $\begin{bmatrix} E[h(t_n,\tau_l)h(t_n,\tau_l)^*] + \sigma_{noise}^2 & \cdots & E[h(t_n,\tau_l)h(t_{n-M+1},\tau_l)^*] \\ \vdots & \ddots & \vdots \\ E[h(t_{n-M+1},\tau_l)h(t_n,\tau_l)^*] & \cdots & E[h(t_{n-M+1},\tau_l)h(t_{n-M+1},\tau_l)^*] + \sigma_{noise}^2 \end{bmatrix}^{-1} \begin{bmatrix} E[h(t_n,\tau_l)h(t_n,\tau_l)^*] \\ \vdots \\ E[h(t_{n-M+1},\tau_l)h(t_n,\tau_l)^*] \end{bmatrix}$

- $\hat{\boldsymbol{h}}_{t_{n,..,n-M+1};\tau_l} = \begin{bmatrix} \hat{h}_{t_n,\tau_l} \\ \vdots \\ \hat{h}_{t_{n-M+1},\tau_l} \end{bmatrix}$

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THANK YOU!

QUESTIONS ?