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

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Abstract—**With the ever increasing usage of wireless devices, the power consumption and energy efficiency of cellular networks have become important performance indicators. In recent years, various types of energy saving schemes have been proposed for cellular networks. However, most of these schemes do not take advantage of the advanced features offered by the recent cellular standards, such as the 3GPP release 10 (also known as LTE-Advanced) and beyond. One of the recently proposed energy saving schemes in cellular networks is the cell switch off technique in which a lightly loaded cell is completely switched off and the traffic in that region is absorbed by the nearby cells whose transmit powers are increased to enable larger coverage areas. In this paper, we propose to use the cell switch off scheme without increasing the transmit powers of the active cells; instead, we propose to use the coordinated multipoint (CoMP) transmission radio technology, which is being standardized for the beyond-LTE cellular networks, to enable a sufficient received power level from a number of nearby cells whenever possible. Through simulations with realistic parameters, we demonstrate that the above described cell switch off + CoMP combination used with proper CoMP active set degree yields a more energy efficient solution with better received user experience in comparison to the traditional cell switch off schemes. In the proposed scheme, channel estimations are needed in order to determine the CoMP active set accurately. We analyze the performance by modeling the channel estimation error as a Gaussian random variable with 4, 8, and 12 dB standard deviation and observe that perfect channel estimation can provide up to 46% capacity and 24% energy efficiency increase in comparison to the scenarios with the channel estimation errors.**

I. Introduction

Recently, the development and enhancements in wireless communications not only focus on increasing the data rates, capacity or spectral efficiency, but also on implementing energy saving methods. This is mostly due to the observation of high energy consumption resulting from information and communications technologies and mainly wireless access networks. The ICT (Information and Communications Technology) is responsible for 2-10% of the global energy consumption and the access networks (GERAN for GPRS, UTRAN for UMTS and e-UTRAN for LTE) are responsible for 60-80% of the whole cellular network energy consumption [1]. As a consequence, optimizing the wireless access stratum plays a more important role in overall energy savings in cellular architectures compared to the core network energy efficiency.

Various green techniques have been proposed recently for the wireless access networks with different optimization methods using various energy efficiency and trade-off metrics. A detailed survey on motivations for green cellular networks and different methods for energy savings is presented in [2] and categorized under energy savings via cooperative networks, renewable energy resources, heterogonous networks and cognitive radio. Although there are methods to sustain long term energy savings by reducing peak user demand as proposed by authors of [3], access network energy savings are mostly implemented by cell size adjustments according to traffic load fluctuations. Authors of [4] proposed a scheme where cells with the low traffic zoom into zero, and the neighbor cells zoom out by physical adjustments. Proposed algorithm loops through all the users by assigning user – base station pairs yielding highest spectral efficiencies, and the base stations with the lowest traffic load are turned off. A 24-hour traffic routine that monotonically decreases half of the day and symmetric around mid-day is analyzed in [5] and [6]. The optimum time to start and stop the energy saving period is found to switch off the low traffic cells and results show 20% energy saving increases. The algorithm presented in [7] converges to an optimal switch off ratio with the necessary transmission power increase in the remaining cells and the maximum energy savings in the access network where the traffic is modeled as a Markovian arrival process. Authors of [8] focused on finding the optimal cell sleeping strategy by taking the ratio between the dynamic and the fixed power of a base station as a decision parameter. It is shown that the power ratio increases due to the traffic load increase make the dynamic power dominate over the constant power and more base stations should be active to save energy in the system. All the schemes mentioned above focus on access network energy savings via various methods of cell switch off mechanisms using theoretical models for radio wave propagation and small scale fading. Authors of [9] analyzed the standalone energy efficiency of an upcoming radio technology feature, namely CoMP, and authors of [4] mentioned CoMP as an advantageous method for cells to zoom out, however, joint use of CoMP feature with traditional cell switch off schemes is not analyzed in any literature, to the best of our knowledge.

In this paper, we investigate using an LTE-advanced feature CoMP in the downlink which is used jointly with the existing cell switch off energy saving schemes. Increasing the transmit power method in the remaining active cells during the energy saving period is replaced by the remaining active cells using CoMP to jointly serve the users in the system. Realistic wireless channel and propagation models in accordance to 3GPP specifications are used throughout our work. Our results show that cell switch off schemes used jointly with downlink CoMP is more energy efficient in the access networks. Performance analysis for this scheme is also executed taking

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into consideration the possible channel estimation errors in the system.

The rest of the paper is organized as follows. Sec. II describes the cellular model used in our study. Sec. III presents a performance comparison of traditional cell switch off schemes with our proposed model in stationary channels, Sec. IV analyzes the downlink capacity and energy efficiency performance of cell switch off with CoMP schemes in faulty channel estimation scenarios and Sec. V concludes the paper.

II. Cellular System Model

A. Coordinated Multi-Point Transmission

CoMP is a key feature in LTE-Advanced and beyond technologies which is considered under the distributed antenna systems umbrella that needs to be analyzed for energy saving implementations. Scope of this paper is limited to downlink CoMP usage in cellular networks. Definition of CoMP is explained initially in 3GPP 36.814 [10] as dynamic coordination among multiple geographically separated points referred as CoMP cooperating set for downlink transmission and uplink reception. CoMP cooperating set is defined as the geographically separated points that are participating in the Physical Downlink Shared Channel (PDSCH) transmission either directly or indirectly. Joint processing - joint transmission CoMP scheme is considered in our scheme where the downlink payload and data is available at each point in the CoMP cooperating set and downlink payload is transmitted on PDSCH from multiple points in the CoMP set. Serving cell is responsible for using the Physical Downlink Control Channel to send System Information Blocks to the UE (User Equipment) controlling the resource allocation, HARQ information, transport format and power control. Serving cell also coordinates the other participants in the downlink cooperating CoMP set by manipulating UE's feedback for Channel State Indicator (CSI), precoding matrix indicator (PMI) and Rank Indicator (RI) for MIMO over the Physical Uplink Control Channel (PUCCH).

It should also be noted that only the received power from the points outside the CoMP transmission points are treated as interference. This results in significant SINR increases for cell edge users. Received linear SINR for users in the legacy radio technologies like LTE release 8 was calculated as

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

where $P_{serving}$ is the received power from the serving cell, P_i is the received power from the ith interfering cell and K is the number of interfering co-channel cells. In a cellular system using downlink CoMP, the received SINR is calculation is shown in [11] assuming a receiver performing a perfect phase adjustment for alignment of sinusoidal crests as

$$SINR_{CoMP} = \frac{P_{serving} + P_j + P_m}{\sum_{\substack{i=1 \\ i \neq j,m}}^{K} P_i + P_{Noise}}, \quad (2)$$

where P_j and P_m are the received powers from cells participating in the downlink CoMP cooperating transmission set of a 3-cell cluster as shown in Fig. 1.

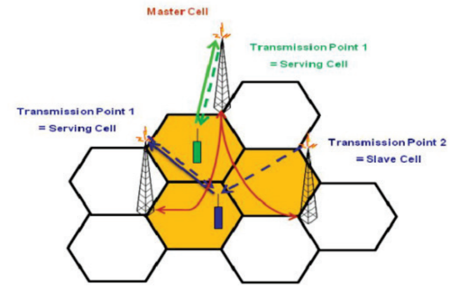

Fig. 1. CoMP transmission for CoMP set degree: 3 (taken from [11]).

Spectral efficiency increase in downlink CoMP systems comes along with additional backhauling and signal processing trade-offs that increase the power consumption of a base station participating in CoMP. Total power consumption in Joules/sec for a base station using CoMP is calculated using the assumptions from [12] and [13] as

$$P_C = N_s * N_{\frac{PA}{sector}} * \left(\frac{P_{TX}}{PA_{eff}} + P_{SP}\right)(1 + C_C)(1 + C_{PSBB}) + P_{BH}, \quad (3)$$

where N_s is the number of sectors, $N_{PA/sector}$ is the number of power amplifiers per sector, P_{TX} is the transmit power of the base station, PA_{eff} is the power amplifier efficiency, P_{BH} is the power consumption due to CoMP backhauling, C_C and C_{PSBB} denote the cooling and battery backup losses in the system. In (3), P_{SP} is the signal processing in the base station which has a base value of 58W for an LTE e-NodeB mentioned in [13], however the signal processing increase due to CoMP is modeled in [12] with the below equation as a quadratic function of the CoMP cooperating set degree N_C for values of $N_C \geq 2$:

$$P_{SP-CoMP} = 58 * (0.87 + 0.1 N_C + 0.03 N_C^2). \quad (4)$$

Backhauling power consumption P_{BH} for base stations using CoMP is modeled in [12] as

$$P_{BH} = \frac{C_{BH}}{100Mbits/sec} * 50W, \quad (5)$$

where C_{BH}, the additional backhaul data capacity needed, is expressed as

$$C_{BH} = \frac{N_c * (2N_C) * p * q}{T_S} \; bits/sec, \quad (6)$$

where p and q represent the additional pilot density and CSI signaling due to CoMP, respectively, and $T_S = 66.7\mu sec$ is the symbol period which is the reciprocal of the assumed OFDM sub-carrier spacing of 15 kHz. For base stations that are not using CoMP in the downlink $P_{SP-Base}$ is 58 W and P_{BH} does not exist.

B. Large Scale Propagation & Pathloss Model

Pathloss models defined in the 3GPP specifications by ITU after actual field measurements are used in this paper according to ITU-R report M.2135 for radio interfaces in [14] instead of the classical log-normal shadowing model to have a more realistic model and feasible results. Urban Macro (UMa) pathloss model is used according to the below equations and parameters specified in Table 1 with respect to ITU for line of sight (LoS) and none line of sight (NLoS) scenarios. LoS probability is modeled as a Bernoulli random variable:

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

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

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

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

TABLE I. Simulation Parameters for UMA Pathloss Model

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

Received signal power due to spatial pathloss versus propagation distance is obtained in Fig. 2. It can be seen that the Bernoulli line of sight probability decreases with increasing BS-UE distance d and the received power spikes decrease as expected.

C. Small Scale Fading and Multipath Model

Received signal at the mobile receivers usually consists of multipath components, which are, radio waves propagating from different directions with different amplitudes and phases due to scattering, diffraction, reflection, refraction and absorption. The received signal $s(t)$ due discrete multipath channel impulse response and the Doppler shifts of each different multipath due to relative motion is derived as

$$s(t) = \sum_{n=0}^{N-1} A_n * \cos(2\pi f_c t + 2\pi f_{d_n} t + \phi_n), \qquad (7)$$

where N is the total number of multipath components, f_c is the carrier frequency, f_{d_n} is the Doppler shifts of each multipath and ϕ_n is the phase differences due to various path lengths of the components. Both the amplitudes A_n and phases ϕ_n are modeled as independent identical random variables where ϕ_n is a uniform random variable with a range [0, 2π]. Slow – flat fading channel is assumed in our simulations where the bandwidth of the signal B_{signal} is smaller than the coherence bandwidth B_c of the channel and accordingly the delay spread σ_τ of the channel being smaller than the symbol period T_{symbol} of the signal. As a result no distortion is observed in this model but the due to the narrowband signal the amplitude has deep fades over time. Small scale fading model from [15] which takes the 3GPP specification (25.996) as a basis for implementation is used in our simulations with the input parameters expressed in Table 2.

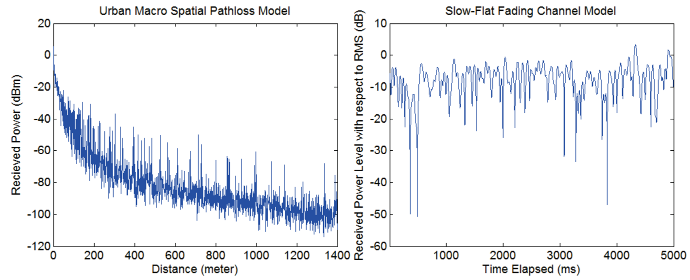

Fig. 2. Large scale pathloss and small scale multipath fading models.

TABLE II. Simulation Parameters for Slow-Flat Fading

Channel Parameters	Value
Number Multipath Components (N)	6
Sampling Density (n)	170.616 samples / (λ/2)
Mobile Receiver Antenna Speed (v)	6 km/h
Number of Time Samples (T)	20000

Channel samples are converted to time domain using the spatial sampling interval as

$$Time\ Elapsed/Channel\ Sample = \frac{(\lambda/2)/n}{v}, \qquad (8)$$

where λ is the wavelength that is found by using the downlink carrier frequency, n is the sampling density used in the simulation specifying the number of channel samples per half wavelength traveled by the mobile receiver antenna and v is the velocity of the mobile receiver antenna. Therefore the sampling density is tuned to 170.616 yielding channel sample duration of 0.25 ms and 4 samples per transmitted time interval (TTI). Complex baseband channel impulse response is expressed by a 2-dimensional array N x T. Power gain was found by summing the channel impulse response over the multipath components to get the overall impulse response over a single spatial channel sample by

$$H_{total}(t, 1) = \sum_{n=1}^{6} H(t, n), \qquad (9)$$

where t is the index for the channel samples and n is the index for the multipath components. A single array containing the overall channel impulse response resulting from the multipath components during each sample is expressed by H_{total}. Power gain (dB) of the received signal for each channel sample is found by

$$\text{Power Gain (dB)} = 10 * \log_{10}[(\frac{\text{abs}(H_{total})}{2})^2], \qquad (10)$$

which is then plotted against the time elapsed in milliseconds that is found by converting the spatial channel samples to time duration using the previously mentioned methodology. Resulting graph containing the received signal power gain in dB with respect to the RMS value due to small scale fading is demonstrated in Fig. 2. The RMS received power of the signal due to spatial location of the mobile stations and shadowing are calculated by using the model described in Sub-section B.

D. Uniform User Distribution

Hexagonal cellular network layout of 19 cells with base stations located in the center of the cells with omni-directional antennas is considered with a cluster size and frequency re-use factor of one. The center cell represents the original serving cell with 18 remaining cells representing 3 tiers of co-channel interferers. Energy saving calculations are done for the serving cell which is switched off and the remaining active cells have the capability of using downlink CoMP to serve the users in the switched off cell. According to the hexagonal cell geometry with cells having identical cellular radii R, the inter-BS distance can be expressed as $R\sqrt{3}$ which is set to 500 m according to urban macro cellular layout. User coordinates in the network are generated using polar coordinates with θ denoted by a uniform random variable such that $0 < \theta < 2\pi$ and R generated by taking the square root of a uniform random variable X such that $0 < X < 500 / \sqrt{3}$ and $R = \sqrt{X}$. The square root of the R coordinate is taken to obtain perfect uniformity in a circular spatial area.

III. Energy Efficient Cell Switch Off Schemes

This section compares the performance of traditional cell switch off schemes with the proposed scheme where the remaining active cells use CoMP during the energy saving time period to serve the users in the switched off area. Stationary users are assumed in this section with pathloss model according to Sec. II-B. Traditional switch off scheme is modeled where the remaining active cells are assumed to increase their transmission power P_{TX} by 2 W each to serve the users whereas in the CoMP scheme the remaining cells keep the same transmission power. CoMP set degree N_C up to 6 is simulated where N_C cells with the highest received power for each UE are participating to serve the specific UEs. As a result, each user can have different cells participating in CoMP. In the simulations, a total of 500 users are populated in the switched off cell uniformly and the received downlink capacity C_i for each user i is found according to Shannon's capacity formula for each scheme:

$$C_i = BW_i * \log_2(1 + SINR_i)\,. \tag{11}$$

In the above, BW_i denotes the bandwidth assigned to the user i which is set to 4.5 MHz assuming no scheduling done over the TTI and 0.5 MHz is allocated for guard band which is 10% of the overall 5 MHz bandwidth available in the LTE system. Received SINR for each scheme is found by (1) and (2) assuming noise spectral density of -174 dBm/Hz. CDF of the downlink capacity for each scheme is shown in Fig. 3 and it is clear that the proposed scheme of using CoMP jointly with traditional cell switch off schemes yield higher capacity. Increasing the CoMP set degrees up to 6 resulted in further improvement in the overall received QoS in terms of capacity especially for the cell edge users which are defined as the 5% of the capacity CDF. Energy efficiency of each user i, EE_i, in terms of bits/Joule is found by

$$EE_i = C_i / Ptotal_i\,, \tag{12}$$

where the total access network power consumption for each user $Ptotal_i$ is found using (4), (5) and (6) as

$$P_{Total} = P_{BS-Base}\,, N_C = 1 \tag{13}$$

for traditional schemes without CoMP, and as

$$P_{Total} = P_{BS-CoMP} + (N_C - 1) * (P_{BS-CoMP} - P_{BS-Base})\,, N_C \geq 2 \tag{14}$$

for the proposed scheme.

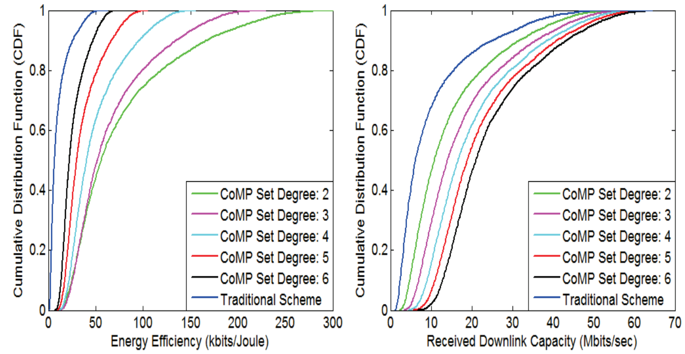

Fig. 3. Comparison of traditional and proposed cell switch off schemes.

All the CoMP schemes up to $N_C = 6$ yielded better energy efficiency than the traditional cell switch off schemes as it can be seen in Fig. 3. The surprising result of the simulations is that increasing the CoMP set degree blindly from $N_C = 2$ to $N_C = 6$ in fact decreases the bits/Joule energy efficiency of the system proving that excess usage of CoMP in the downlink can lead to worse performance due to signaling and backhauling overhead in the network.

IV. Performance analysis of Energy Efficient CoMP Transmission Scheme

Advantage of using CoMP transmission in the downlink is very clear in terms of increasing the received SINR values of the users in the cellular network. However unnecessary use of CoMP can cause high energy inefficiency in the system due to excess signaling between the cooperating set as shown in III. To avoid this, there is a need for threshold to limit the CoMP cooperating set as defined in [16]: *"The cell edge UE to which CoMP transmission is applied is defined to be when the difference in the UE path loss between the serving cell and the second strongest cell is within 3 dB"*. Performance of CoMP energy saving schemes in dynamic wireless channels with downlink channel estimation errors is analyzed using the 3 dB constraint. Using the aforementioned large scale pathloss scheme for Urban Macro pathloss with the small scale fading scheme, we demonstrate independent dynamic channels for each user over 1000 channel samples (250 TTI). Applying the 3 dB rule to obtain the CoMP transmission set, the average number of needed CoMP cooperating base stations $NComp_{i,t}$ is found for each channel sample t considering the uniformly distributed users i in the serving cell assuming all the users perform perfect channel estimation for received powers. To observe the effect of imperfect channel estimation for the users Gaussian channel estimation error is assumed for all the channel samples. Imperfect downlink channel estimation for the users result in wrong CSI feedbacks and the number of participating cells in the CoMP set change accordingly. Each user's required CoMP set degree is simulated over 1000 channel samples both for the perfect channel estimation and the channel estimation with Gaussian error scenario. Uniformly distributed 2000 user locations N_{user} are simulated and the average CoMP set degree is found for each channel sample by averaging over all users. Different channel estimation errors are modeled with a Gaussian random variable having 0 dB mean and various standard deviation values as 4, 8 and 12 dB. It can be seen from Fig. 4 that the channel estimation errors result in a reduction in overall CoMP use especially for the cell edge users in the system and as the channel estimation errors increases the CoMP use decreases further. Capacity $C_{i,t} = BW_i * \log_2(1 + SINR_i)$, and energy efficiency $EE_{i,t} = C_{i,t}/Ptotal_{i,t}$ of each user i for each channel sample t is obtained and averaged over all users for each channel sample. Capacity losses up to 0.71 Mbits/sec and energy efficiency degradation up to 4.53 kbits/Joule are observed when comparing the perfect channel estimation case with the faulty CSI scenario due to 12 dB standard deviation Gaussian estimation error scenario. Averaging the perceived capacity and the energy efficiency over all the users for each channel sample gives a general idea about the impacts of incorrect CSI feedbacks due to channel estimation errors, however the real impact should be considered for cell edge users since their performance is highly dependent on CoMP usage. Therefore, CoMP set degree, energy efficiency and received downlink capacity for each user is calculated by averaging over 1000 channel samples t as

$$NComp_i = \frac{\sum_{t=1}^{\max(t)} NComp_{i,t}}{\max(t)},\ EE_i = \frac{\sum_{t=1}^{\max(t)} EE_{i,t}}{\max(t)},\ C_i = \frac{\sum_{t=1}^{\max(t)} C_{i,t}}{\max(t)}, \quad (15)$$

where $NComp_i$ is the required CoMP set degree, EE_i is the energy efficiency and C_i is the received downlink capacity for user i averaged over all the channel samples t. Calculations are again done for all the 4 scenarios as mentioned earlier. Users are then sorted with ascending received SINR order and plotted against the performance metrics energy efficiency, received capacity and number of CoMP set degrees. It can be understood from the Fig. 5 that the impacts of passing incorrect CSI feedback to the CoMP serving cells due to channel estimation errors become more severe for cell edge users. When considering the cell edge users, involved CoMP set degree losses up to 47% are observed due to channel estimation errors. These result in 46% received downlink capacity and 24% energy efficiency degradation compared to perfect channel estimation scenarios.

V. Conclusions and Future Work

In this paper, we analyzed an alternative way of improving the cell switch off schemes for further energy saving enhancements using CoMP transmission technique and proved the advantages in terms of both energy and capacity efficiency. We also identified the sensitivity of the CoMP scheme to channel estimation errors in dynamic channels that lead to incorrect CSI feedbacks. Both imperfect downlink channel estimations and the unnecessary CoMP set degree increases can lead to energy inefficiency in the cellular systems in terms of bits/Joule. Future work will focus on implementing channel prediction schemes that improve CoMP energy efficiency even further for cell switch off schemes under dynamic channel conditions.

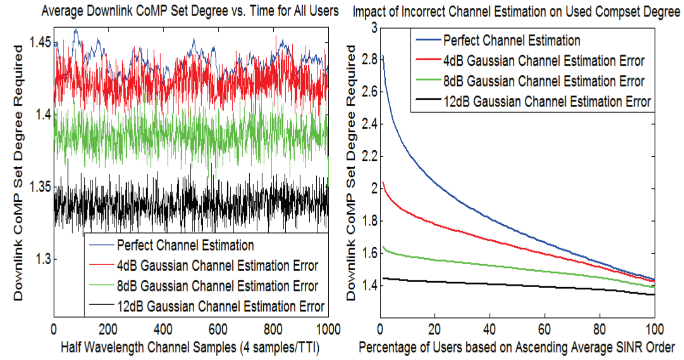

Fig. 4. CoMP set degree change in dynamic wireless channels both for perfect and incorrect channel estimation scenarios

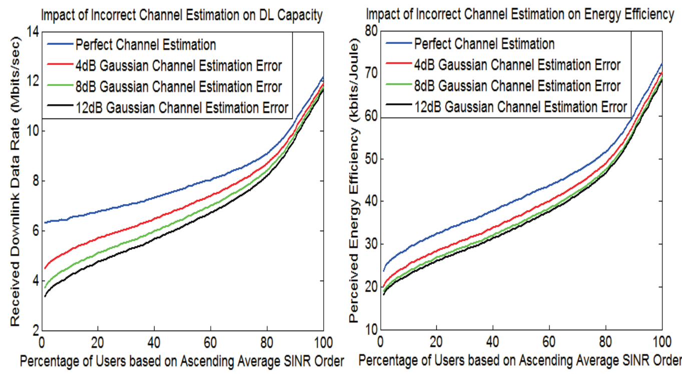

Fig. 5. Energy efficiency and capacity change in CoMP systems used jointly with cell switch off schemes in dynamic wireless channels

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