



Performance Analysis of Energy-Efficient Cell Switch off Scheme for CoMP Networks

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Abstract. In this paper, a joint power and subcarrier optimization problem to minimize the network energy consumption with considerations of dynamic Coordinated Multipoint Transmission (CoMP) clustering, user quality of service (QoS) requirement and base station (BS) load is formulated for cell switch off in CoMP transmission scenario. Since the complexity of such optimization problem is prohibitive in practical application, following the manner of dynamic programming (DP), the original problem is decomposed to a sequence of sub-problems on cell switch off with dynamic CoMP clustering and system transmit power optimization. Then the Cluster Load Search, User Sum SINR and Cell Sum Load Based Clustering Schemes are proposed for cell switch off evaluation. The simulation results show that the proposed schemes achieve competitive network energy-efficient performance compared with benchmark optimization scheme while at the same time save up to 40% of the overall overhead.

Keywords: Coordinated Multipoint · Cell switch off · Energy efficiency

1 Introduction

It is widely accepted that switching off the Evolved NodeB (eNB) which is not fully loaded is an effective way to improve system energy efficiency [1]. However, in current cell switch off schemes, neighboring cells are usually required to increase transmit power to enlarge their coverage and handover the traffic of the switched off cells [2], and thus result in degradation of energy saving performance from the view of the whole network.

Coordinated Multipoint (CoMP) technology has been noticed for its advantage in interference avoidance and spectrum efficiency enhancement [2–6]. Naturally, the combination of CoMP and cell switch off in cellular network is a promising approach for energy saving [7] without increasing the transmit power of the active cells.

However, detailed power consumption models for eNB with CoMP transmission was missing until the contribution of [8] and [9]. Compared with power consumption model from Energy Aware Radio and neTwork TecHnologies (EARTH) project [10], the power consumption for additional signal processing and backhauling were introduced by [8] and [9] and thus made these models more accurate for CoMP application. Based on these power consumption models, [11] studied the improvement of energy saving gain and energy consumption ratings (ECR) for CoMP and Non-CoMP systems. The comparison of energy efficiency performance between different cooperative modes (dynamic cell selection (DCS), joint transmission (JT) and coordinated beam forming (CB)) are presented in [12] and JT is suggested as the most energy efficient mode among all CoMP modes under the same transmit power constraint due to its diversity gain. However, most previous works only discussed the cases with fixed CoMP cluster size and thus limited their application in realistic network. If dynamic CoMP clustering is introduced, the variety of CoMP clustering configuration and discontinuous allocation of subcarriers will render the joint optimization problem a combinatorial optimization problem involving integer variables, and thus requires exhaustive search to find the optimal solution. In most cases, the complexity brought by such exhaustive search is prohibitive and hard for realistic implementation.

The rest of this paper is organized as follows: Sect. 2 describes the cellular network system model. Section 3 introduces the cell switch-off based energy minimization schemes and Sect. 4 illustrates the simulation results. Section 5 gives a conclusion.

2 System Model

2.1 CoMP Transmission

Only joint transmission (JT) mode is considered in this paper for its better energy efficiency performance according to [12, 13, 16]. In JT, the downlink traffic data and payload is available at each point in the CoMP cooperating group and transmitted via Physical Downlink Shared Channel (PDSCH) from multiple eNBs in the CoMP group [2].

Assumes that an M -cell cellular network with base-stations $BS_1 \dots BS_M$ of omnidirectional antennas and random user equipment (UE) location are configured. Let's define set $\mathcal{M} = \{1, 2, 3 \dots M\}$, for non-CoMP scenario, the SINR of user u in serving cell T is:

$$SINR_u = \frac{P_{tx,T} h_{u,T}}{\sum_{q \in \mathcal{M}, q \neq T} P_{tx,q} h_{u,q} + P_{Noise}} \quad (1)$$

Where $P_{tx,T}$ is cell transmit power, $h_{u,T}$ is the large scale channel gain from BS_T to user u . $P_{tx,q} h_{u,q}$ is the received power of the co-channel interfering cells q . P_{Noise} is the noise power.

For CoMP cell switch off scenario as shown in Fig. 1, when a cell T is switched off, one or more of its neighboring cells (i, j, k , for example) enable CoMP transmission to serve UEs in the switched off cell T . Assume that total L neighboring cells participate in this cooperative transmission cluster, which is denoted as CoMP cluster C_T with cluster

size L_{C_T} . Assumes the impact of intra-cell interference could be eliminated by cyclic prefix (CP) of OFDM symbols, according to the definition of CoMP JT, received signals from cells belong to C_T are considered as desired signal, while received signal other than this CoMP cluster are interference. Then the SINR for CoMP scenario is

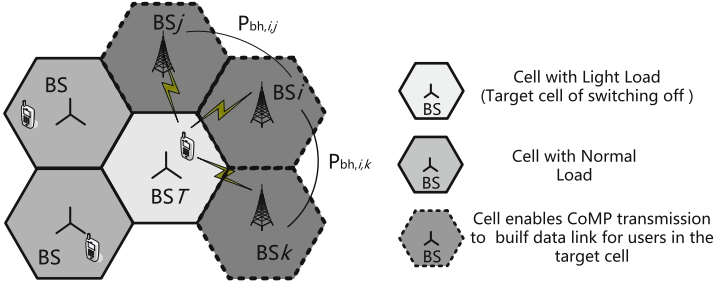


Fig. 1. CoMP Transmission after cell switched off. After switching off the light loaded cell T , the neighboring cells i, j, k enable CoMP transmission to build data link for users original in cell T .

$$SINR_{u,CoMP} = \frac{\sum_{i \in C_T} P_{tx,i} h_{u,i}}{\sum_{j \in M, j \notin C_T} P_{tx,j} h_{u,j} + P_{Noise}} \quad (2)$$

2.2 Power Consumption Model for Cooperative Cells

As in [9], for macro eNB, the overall power consumption can be divided into several parts. Among them, the radio frequency (RF) transmit power and baseband signal processing are most significant ones. Besides, the cooling loss, battery backup and backhauling power consumption between base stations under CoMP transmission should also be considered. Hence, the overall power consumption for eNB macro base station under CoMP transmission is,

$$P_{BS_CoMP} = \left(\frac{P_{tx}}{\mu_{PA}} + P_{sp} \right) \cdot (1 + C_c) \cdot (1 + C_{PSBB}) + P_{bh} \quad (3)$$

where μ_{PA} stands for the power amplifier efficiency, power cooling loss and battery backup loss are denoted as C_c and C_{PSBB} . The eNB transmit power is denoted as P_{tx} , power consumption for signal processing is denoted as P_{sp} while P_{bh} represents the backhauling power consumption.

3 Cell Switch off Based Energy Minimizing Schemes

In this section, the optimization problem for minimum network energy consumption is presented. Since this optimization problem is often very high complexity, it is decomposed into a sequence of dynamic CoMP clustering and cluster energy optimization sub-problems with cell switch off. Finally, three low complexity schemes are proposed for solving the sub-problems.

3.1 Optimization Problem

The optimization problem for minimum network power consumption is given by:

$$\min_{P_{tx}, S_f, W} P_{\text{network}} = \sum_{i=1}^M P_{\text{BS},i} \quad (4)$$

$$s. t. R_{u,i} = \begin{cases} W_{u,C_T}^{S_f, C_T, L_{C_T}} \log_2(1 + SINR_{u,T,CoMP}) \geq D_{u,i}, \forall u \in K_T \\ W_{u,i} \log_2(1 + SINR_{u,i}) \geq D_{u,i}, \forall u \in K_{C_T} | \forall u \notin K_T \end{cases} \quad (4a)$$

$$\sum_{u=1}^{K_i} N_{u,S_f, C_T, L_{C_T}} \leq N_{w,i}, \quad \forall i \in M \quad (4b)$$

$$L_{C_T} \in \mathbb{Z}^+ \text{ for } \forall C_T \quad (4c)$$

In order to avoid any coverage issue, constraints (4a) and (4b) are proposed, where (4a) represents the achievable user data rate for user u of cell i should be no less than its demanded rate $D_{u,i}$ in both CoMP and non-CoMP cells, to fulfill the user QoS requirement. The notion $S_{f,C_T,L_{C_T}}$ defines the cell combination set of CoMP cluster C_T with size L_{C_T} (4b) set a limitation that the total TFRB requirements from all K_i users in cell i should be no more than the overall available TFRB resource for the cell. (4c) guarantees that the CoMP cluster size is a positive integer for all clusters.

The optimization problem (4) is a combinatorial optimization problem not only because finding the optimal cell combination set $S_{f,C_T,L_{C_T}}^*$ for cluster C_T is an NP-hard problem but also the allocation for discontinuous subcarrier $W_{u,C_T}^{S_f, C_T, L_{C_T}}$ for user u and real continuous variable of transmit power $P_{tx,i}$ for cell i .

As a result, one approach to solve problem (4) is exhaustive search with iteration on $P_{tx,i}, W_{u,C_T}^{S_f, C_T, L_{C_T}}$ and all possible cluster configurations. However, the complexity of such search is not acceptable for most systems. In order to reduce the complexity, some algorithms, like that in [14], relaxed $W_{u,C_T}^{S_f, C_T, L_{C_T}}$ to continuous variable and fixed the CoMP cell combination $S_{f,C_T,L_{C_T}}$ with few constant L_{C_T} categories, and converts the power-frequency allocation problem to convex problem. But fixed CoMP cluster size will limit the algorithm's application in real network. Hence, dynamic CoMP cell clustering is proposed in this paper.

In order to reduce the complexity of (4), according to DP, the optimization problem is decomposed to several sequential sub-problems (also known as DP stages) each, with single cell switch off. In each of them, dynamic CoMP clustering and BS transmission power optimization is considered. Then assumes $W_{u,C_T}^{S_{f,C_T,L_{CT}}*}$ a continuous real variable that can be allocated based on user rate requirement and received SINR. Since in the original problem, $W_{u,C_T}^{S_{f,C_T,L_{CT}}}$ is an integer number, there is certain degradation caused by rounding error when mapping the obtained $W_{u,C_T}^{S_{f,C_T,L_{CT}}*}$ to $W_{u,C_T}^{S_{f,C_T,L_{CT}}}$ in (4). However, if suppose the total available frequency subcarrier resource is much larger than the number of users, then the allocated number of subcarriers for each user is significantly larger than the rounding error, the degradation is acceptable.

Therefore, problem (4) is reformulated as a DP problem with time sequentially sub-problems (5) on minimizing cluster energy consumption as:

$$\min_{P_{tx}, S_f, W} P_{\text{cluster}} = \sum_{\substack{i=1 \\ i \in C_T}}^L P_{\text{BS},i} \quad (5)$$

$$s. t. \quad R_{u,i} = \begin{cases} W_{u,C_T}^{S_{f,C_T,L_{CT}}*} \log_2(1 + \text{SINR}_{u,T,\text{CoMP}}) \geq D_{u,i}, \forall u \in K_T \\ W_{u,i} \log_2(1 + \text{SINR}_{u,i}) \geq D_{u,i}, \forall u \in K_{C_T} | u \notin K_T \end{cases} \quad (5a)$$

$$\sum_{u=1}^{K_i} N_{u,S_{f,C_T,L_{CT}}} \leq N_{w,i} \quad \forall i \in M \quad (5b)$$

$$L_{C_T} \in \mathbb{Z}^+ \quad \text{for } \forall C_T \quad (5c)$$

Problem (5) can be further decomposed to an integer optimization problem on the combination of $S_{f,C_T,L_{CT}}$ and L_{C_T} , and a convex problem on the allocation of $W_{u,C_T}^{S_{f,C_T,L_{CT}}*}$ and $P_{tx,i}$. The convex problem can be solved by power and subcarrier optimization with efficient tools from [15], while for the integer optimization problem, three low complexity cell switch off schemes are proposed in this paper to obtain the optimal $S_{f,C_T,L_{CT}}$ with dynamic L_{C_T} for each sub-problem.

The energy saving performance of proposed schemes are impacted by parameters such as subscriber scale, user rate demands, cell transmit power, bandwidth and cluster size. For the convergence consideration, cell load as well as user rate demand are checked during each iteration. During the optimization iteration of cell switch off, if the cell load limit is reached, the iteration will break and a test of smaller cluster size will be initiated. If all the cluster sizes are not applicable for the current sub-problem, a new target cell will be obtained and corresponding cell switch off problem will be initiated. If the proposed schemes are not applicable for any cell in the pre-set network, it will get terminated.

4 Simulation Results

The parameters are listed in Table 1 in accordance with [8, 14]. Assume perfect channel information sharing among CoMP cells and Zero-Forcing Beamforming (ZF) is employed in CoMP-JT downlink transmission, which is widely used with low complexity [14]. The wrap-around technique is applied in our simulation.

Table 1. Simulation parameters.

Parameter	Value
No. of subscribers per cell	2, 4, 6, ... 60
Network configuration (Size and BS type)	19 cells with Macro BS
Cell diameter	500 m
BS Maximum RF output power $P_{tx, max}$	46 dBm
Minimum user rate	256 kbps
Maximum user rate	1.5 Mbps
eNB signal BW	10 MHz
No. of CoMP cluster size L_{C_T}	2, 3, 4, 5, 6
Power density of thermal noise P_{noise}	-174 dBm/Hz
Shadow Fading	Log-Normal, $\sigma = 6$ dB
Propagation & Pathloss mode	PL _{LOS} (dB) = 131 + 42.8lgd, d in km
Power amplifier efficiency μ_{PA}	38.8%
Power supply and battery backup factor P_{PSBB}	11%
Cooling factor C_c	23%
Baseline signal processing power consumption p_{sp}	58 W
Backhauling efficiency μ_{BH}	0.5 W/Mbps
Signal power fractions $\gamma_1 = \gamma_2$	0.001
Backhauling additional pilot density fraction p	8/168
Backhauling additional signaling fraction q	8

The normalized network energy saving performance is shown in Fig. 2 for different clustering schemes after a single cell switches off. Thanks to the exhaustive search for all the possible cell combinations for CoMP cluster C_T , CLS cell switch-off scheme results in better performance compared with sum-LOAD and sum-SINR schemes. On the contrast, the sum-SINR based cell switch-off scheme achieves comparative energy saving performance with CLS but less complexity. The sum-LOAD scheme results in the worst energy saving performance due to the introduction of user QoS requirement to the clustering scheme and that makes the $S_{f, C_T, L_{C_T}}$ * estimation affected much more by the user behavior.

The average network energy saving gain after a single cell switch off under different L_{C_T} are compared in Fig. 2. The result shows that in a typical homogeneous network with macro eNB, the network energy saving decreased largely with more users

in each cell due to user QoS requirement and backhauling between CoMP cells. It is also found that larger CoMP cluster has advantage for applications with fewer users per cell. With the increase of user density, the energy consumption by additional signal processing and backhauling between CoMP cells degrade the power saving performance of larger CoMP clusters.

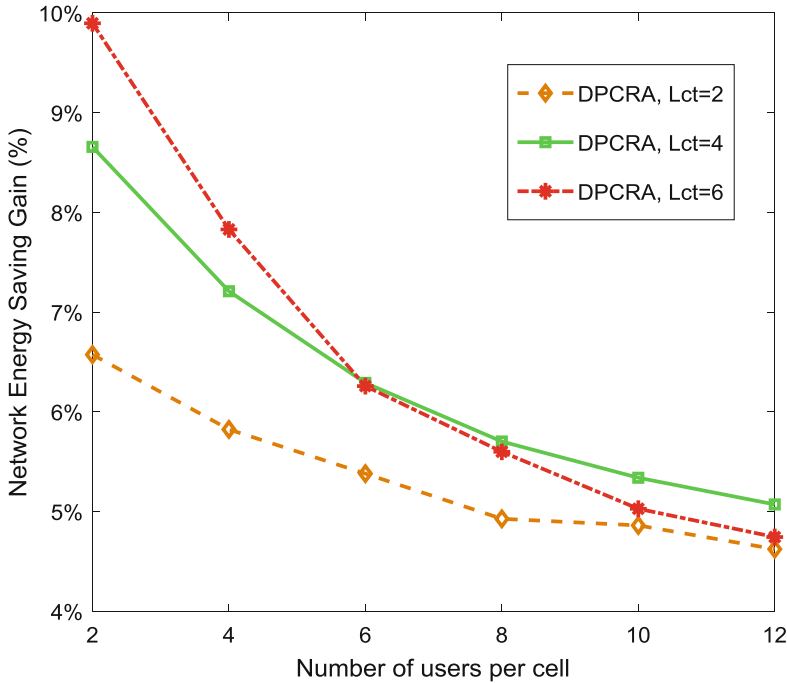


Fig. 2. Network energy saving gain with different L_{ct} , User rate = 256 kbps.

As illustrated in Fig. 3, the energy efficiency performance after a single cell switch off is compared for different average user rate requirements, which reveals that it's harder to support more users or higher average data demands within the same cluster. This figure also clearly shows that outage points are reached after the increase of users per cell and therefore the iteration stops with no upgrade. In Fig. 3, the switch off scheme of sum-SINR with fixed eNB power is also simulated, which provides a lower EE performance until the outage points are reached.

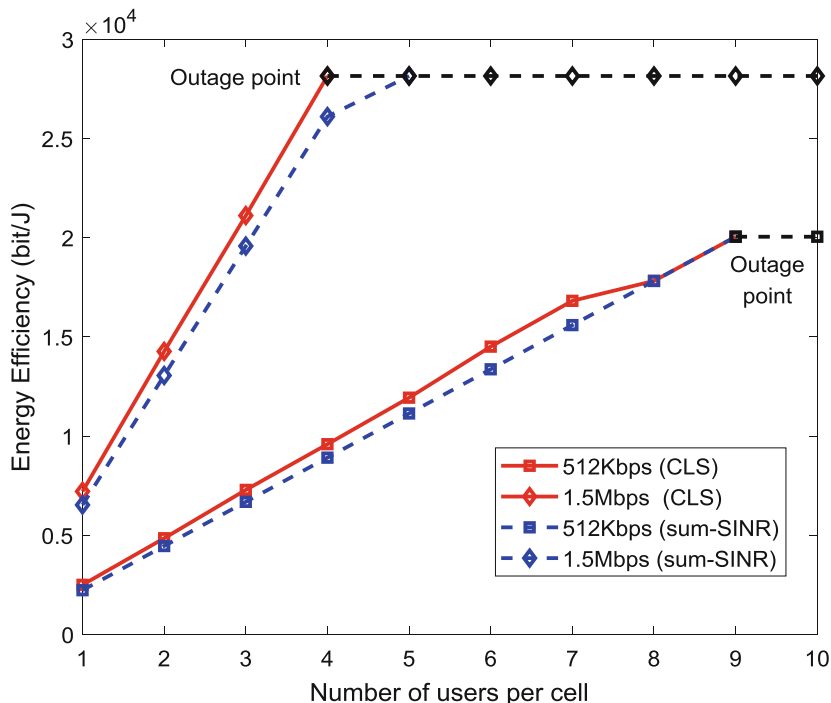


Fig. 3. Energy Efficiency (EE), average user rate = 512 kbps, 1.5 Mbps.

5 Conclusions

In this paper, in order to reduce the complexity of the combinatorial problem of CoMP clustering in each DP stage, three low complexity clustering schemes are proposed in this paper. Simulation results show the Cluster Load Search Based Scheme (CLS) has the best energy saving performance but the worst in complexity. The sum LOAD based scheme requires lower complexity but worst in the energy saving performance. The sum SINR based scheme has a competitive energy saving performance with CLS while has the lowest complexity. The following work based on the proposed schemes could be the study of its effectiveness under different network scenarios, such as HetNet and Hyper-dense network.

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