Energy Efficient Add/Drop Approach for Pico-Cells in Heterogeneous Networks

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Abstract – **In this paper we propose an approach for finding a Heterogeneous Networks (HetNet) Long Term Evolution (LTE) operation scenario which leads to minimization of both the overall downlink power of the Base Stations (BS) in the cell and uplink power of the users. The approach is based on the facts that the transmitted downlink power of a BS is dependent on their load and the uplink power is dependent on the distance of the users from the serving BS. The development of an energy efficient operating solution from both base station and user point of view introduced in this paper is based on a power model for the LTE HetNet and an add/drop heuristic activating procedure for different operation modes of pico BS located in the serving area of the LTE evolved Node Base (eNB).**

Keywords – **Heterogeneous Networks, Long Term Evolution, Pico Cells, Add/Drop Heuristics.**

I. INTRODUCTION

Heterogeneous scenarios in LTE with macro cells and pico cell deployments besides increasing coverage and throughput in many cases can optimize the energy efficiency of a cellular network. Deploying pico cells is expected to make the cellular networks more power efficient due to the reduction of the transmission power as a consequence of the decrease of the distance between the serving nodes and smaller serving areas. In such cases the energy efficiency of the wireless network is mainly dependent on the overall power consumption of the macro and pico base stations, their transmission power and load. The energy efficiency of such scenarios is investigated in many papers. The analyses consider mainly the deployment phase in order to find the best deployment architectures and scenarios for quantifying the potential macro-offloading benefits in terms of higher date rates and reduction of the energy consumption [1], [2], [3], [4], [5], [6].

Energy consumption of the Macro Base Station (eNB in LTE) and Pico Base Stations (PBSs) is traffic dependent and thus dependent on the number of their associated User Equipments (UEs), or UEs served by the corresponding base station. In 3GPP LTE, an UE is associated with the node from which it receives the highest SINR (Signal to Interference plus Noise Ratio). Sometimes this could result in a load imbalance between the eNB and PBSs in the serving area, thus limiting the user throughput and practically not contributing to the overall energy efficiency. On the other hand energy efficiency is considered in relation with the downlink emitted power from the serving Base Station (BS) and in most cases the uplink power from the UEs is not taken under consideration.

In this paper we propose a dynamic add/drop approach for finding an operation scenario of a LTE cell with PBSs which has an optimum in relation to the energy efficiency of both the overall downlink power of the Base Stations (BS) and uplink power of the users in the cell. This could also be reviewed as a trade-off between the power consumption of the access BSs and UEs.

In the next section we describe the power model for the HetNet scenario, the add/drop approach is explained in section III, in section IV we present some numerical results and the last section concludes this paper.

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II. POWER MODEL FOR HETNET SCENARIO

A typical LTE heterogeneous network scenario is shown in Fig. 1. In the serving area of the eNB are deployed several pico cells. The pico cell in a mobile phone network is served by a low power cellular PBS that covers a smaller area usually deployed in places with dense traffic.

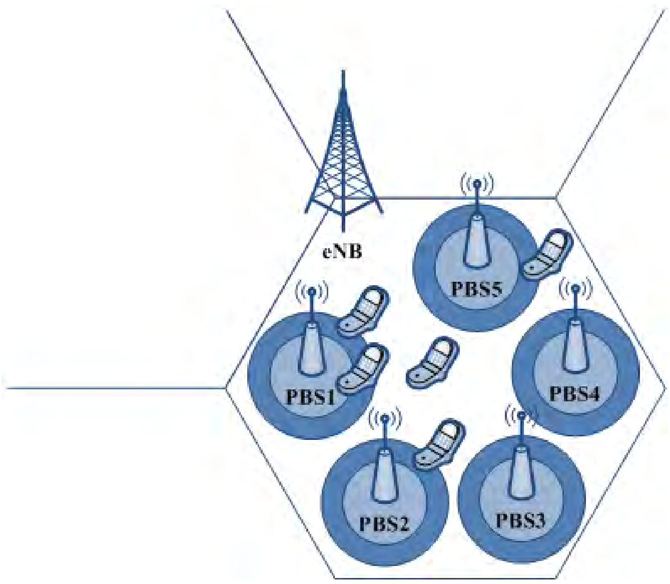

Fig. 1. HetNet scenario

The power models used in this paper are adopted from [7]. The power models of the eNB and PBS are described by a downlink static and a dynamic part as follows:

$$P_{downlink\_one} = \left(P_{static} + P_{dynamic}\right) \quad (1)$$

The eNB static part for one sector is defined as 40% of the maximum downlink power:

$$P_{eNB\_static} = 0.4 * P_{eNB} =$$

$$= N_{PA} * \left(\frac{P_{Tx}}{\mu_{PA}} + P_{SP} \right) * \left(1 + C_C\right) * \left(1 + C_{PSBB}\right) \quad (2)$$

and the dynamic:

$$P_{eNB\_dynamic} = C_{Tx,N_L} * N_L \quad (3)$$

The PBS downlink static part is described as:

$$P_{PBS\_static} = \left(\frac{P_{Tx}}{\mu_{PA}} * C_{Tx,static} + P_{SP,static} \right) * \left(1 + C_{PS}\right) \quad (4)$$

and the dynamic:

$$P_{PBS\_dynamic} = P_{PBS\_dynamic\_link} * N_L, \quad (5)$$

where

$$P_{PBS\_dynamic\_link} = \left(\frac{P_{Tx}}{\mu_{PA}} * \left(1 - C_{Tx,static}\right) * C_{Tx,N_L} + P_{SP,N_L} \right) * \left(1 + C_{PS}\right) \quad (6)$$

The power model parameters are shown in Table I.

TABLE I
POWER MODEL PARAMETERS

Parameters	Descriptions	Values	
		eNB	PBS
N_{PA}	# of power amplifies per sector	2	2
μ_{PA}	Power amplifies efficiency	0.38	0.20
P_{Tx}	Maximum transmit power	39.81	1
P_{SP} [W]	Signal processing overhead	58	-
$P_{SP,static}$ [W]	Static signal processing overhead	-	15
$P_{SP,NL}$ [W]	Dynamic signal processing per link	-	0.55
C_C	Cooling loss	0.29	-
C_{PSBB}	Battery backup & power supply loss	0.11	-
N_L	# of active links	-	50
$C_{Tx,NL}$	Dynamic transmit power per link	1	0.04
$C_{Tx,static}$	Static transmit power	-	0.80
C_{PS}	Power supply loss	-	0.11

Each PBS can operate in the modes off (stand by), active - normal range and active - extended range, the latter being function of the radius of the normal or extended serving area of the PBS.

The uplink power of an UE associated to an eNB or PBS station is defined as:

$$P_{uplink} = \sum_{j=1}^{U} MA_j * P_{tx,j}. \quad (7)$$

Here U is the number of UEs, MA_j are the elements of the matrix of associations MA with values:

$$M_j = \begin{cases} 1; \text{if } UE_j \text{ is associated to a BS} \\ 0; \text{if } UE_j \text{ is not associated to a BS} \end{cases} \quad (8)$$

and the transmit power P_{tx} is calculated from the following equation:

$$P_{tx} = \min\{P_{\max}, P_0 + 10 * \log_{10} M + \alpha * PL\} \quad (9)$$

Here P_{max} is the maximum allowed transmit power which has an upper limit of 23 dBm for UE power class 3, P_0 is the power offset comprising cell-specific and UE specific components, M is the number of physical resource blocks (PRBs) allocated to the UE, α is a cell-specific path loss compensation factor, PL is the path loss estimate calculated at the UE.

For the UEs served by the eNB the path loss is determined in the following way:

$$PL_{eNB} = 131.1 + 42.8 * \log_{10} R \quad (10)$$

For the UEs served by the PBSs the path loss is:

$$PL_{PBS} = 145.4 + 37.5 * \log_{10} R \quad (11)$$

where R is the distance in kilometers.

The total power for the cell (eNB and PBSs) including uplink and downlink is given as:

$$P_{system} = P_{downlink} + P_{uplink} \quad (12)$$

where:

$$P_{downlink} = \sum_{i=1}^{N+1} P_{static,i} + P_{dynamic,i} \quad (13)$$

$$P_{uplink} = \sum_{i=1}^{N+1} \sum_{j=1}^{U} MA_{ij} * Ptx_{ij} \quad (14)$$

III. ENERGY DEPENDENT ADD/DROP ALGORITHM TO USER ASSOCIATION IN HETNET

To determine an optimal energy efficient operating solution from both BS and UE point of view we use add/drop heuristics [8]. The task is to find such an operating scenario (operating modes of the PBSs) which will lead to minimization of the overall downlink power of the eNB and PBSs in the cell and the uplink power of the UE. Practically we propose an algorithm to find the set of active PBSs, which will lead to minimum overall power balance in the cell, based on the assumption that the set is formed through a heuristic activation/deactivation PBSs procedure.

In each step of the algorithm, based on the power model described in section II, we determine the operating mode of the PBS for which P_{system} has minimum:

$$MIN\{P_{system}\} \quad (15)$$

Depending on the radius of the serving area of the PBS (a function of the operating mode – active normal or active extended) a corresponding number of users are served (associated). After determining the PBS mode we apply the add/drop procedure for activating the PBSs and for each case calculate a power parameter reflecting the changes of the overall uplink and downlink power in the cell which we call "power balance", given as:

$$PowerBalance = abs\left(\Delta P_{uplink} + \Delta P_{downlink}\right) \qquad (16)$$

where

$$\Delta P_{uplink} = \left(1 - \frac{P_{uplink}}{P_{uplink\_eNB}}\right) \qquad (17)$$

$$\Delta P_{downlink} = \left(1 - \frac{P_{downlink}}{P_{downlink\_eNB}}\right) \qquad (18)$$

At the end of each step we choose the case which gives:

$$MIN\{PowerBalance\} \qquad (19)$$

To find the most efficient solution and giving the trade-off between the changes of the overall downlink and uplink power in the cell we compare the chosen minimum power balances from each step of the add/drop algorithm and choose for operation scenario the step in which the power balance is minimum. Looking at the matrix of associations for this step we can see the operating mode for each of the PBSs in the cell and its user associations. Based on the MA the corresponding PBSs are activated.

In the case of a number of N pico base stations in the serving area of the eNB the add/drop algorithm is realized in the following steps:

Input calculations:

a) Determination of the elements of the Distant Matrix (Floyd matrix). The Distant Matrix (DM) gives the distance of each UE to the eNB and all of the PBSs in the cell.

b) Calculation of P_{uplink_eNB} and $P_{downlink\_eNB}$ in the case of all PBSs being in mode "OFF" and all UEs being served by the eNB.

PBS Add/Drop procedure:

Step 1:

a) Based on the DM, a matrix of associations (*MA*) is determined in the case when the first PBS is in mode "ACTIVE-NORMAL". All UEs that are not in the normal serving range of this PBS are associated to (served by) the eNB. P_{uplink}, $P_{downlink}$, P_{system} and the *PowerBalance* are calculated.

b) Based on the DM, a matrix of associations (*MA*) is determined in the case when the same PBS is in mode "ACTIVE-EXTENDED". All UEs that are not in the extended serving range of this PBS are associated to the eNB. P_{uplink}, $P_{downlink}$, P_{system} and the *PowerBalance* are calculated.

c) For this PBS the active mode with less P_{system} is chosen to be operating.

d) The calculations of P_{uplink}, $P_{downlink}$, P_{system} and *PowerBalance* are done in the cases of sequentially activating and turning off the rest of the PBSs in the eNB serving area.

e) Based on the results of the calculations above the case with the minimum *PowerBalance* (Eq.19) is chosen, thus determining which PBS will be considered as active for this step.

Step 2:

a) The PBS in the previous step is in active (normal or extended) operating mode thus associating the UEs located in its serving area.

b) Based on the DM, a matrix of associations is determined (*MA*) in the case when one of the rest (N-1) of the PBSs is in mode "ACTIVE-NORMAL". The rest of the UEs that are not in the normal serving range of this PBS are associated to the eNB. P_{uplink}, $P_{downlink}$, P_{system} and the *PowerBalance* are calculated.

c) Based on the DM, a matrix of associations (*MA*) is determined in the case when the same PBS is in mode "ACTIVE-EXTENDED". The rest of the UEs that are not in the extended serving range of this PBS are associated to the eNB. P_{uplink}, $P_{downlink}$, P_{system} and the *PowerBalance* are calculated.

d) For this PBS the active mode with minimum P_{system} is chosen to be operating.

e) The calculations of P_{uplink}, $P_{downlink}$, P_{system} and *PowerBalance* are done in the cases of sequentially activating and turning off the other PBSs in the eNB serving area.

f) Based on the results of the calculations above the case with the minimum *PowerBalance* (Eq.19) is chosen, thus determining the next PBS that will be considered as active for this step.

Steps 3 to N:

These steps are repeated until reaching the value of N, which is the number of the PBSs in the cell.

Output:

The algorithm compares the results for the minimum *PowerBalance* (Eq.19) for each step and gives as output the step with least value. Based on the MA for this step the corresponding PBSs are activated.

The advantage of the proposed algorithm is that in each step the number of calculations decreases with N-p, where p is current step of the algorithm. This actually determines it heuristic nature.

IV. Simulation Results

TABLE II
SIMULATION INPUT DATA

Number of users	50
Number of PBSs	5
PBS operating modes: Active-normal Active-extended	20 m coverage 30 m coverage
Static eNB downlink power – Eq. (2)	186.45 W
Static PBS downlink power – Eq. (4)	21.09 W
Dynamic downlink eNB power per link	1 W
Dynamic downlink PBS power per link – Eq. (6)	0.655 W

To illustrate the algorithm we have developed a simulation scenario. The input data is given in Table II and the simulation results are given in Tables III, IV, V, VI and Fig. 2. From the calculations and the results it could be seen that the power balance is minimum in the third step where active are PBS1, PBS2 and PBS5 in active-extended mode. The associated UEs to each base station are given in Table VI.

TABLE III
DISTANCE MATRIX

	UE1	UE2	UE3	. . .	UE48	UE49	UE50
eNB	124.93	110.29	128.61	. . .	58.32	118.83	94.37
PBS1	16.35	8.82	8.11	. . .	103.46	163.97	139.51
PBS2	165.83	173.7	169.75	. . .	262.1	322.62	298.16
PBS3	194.46	200.3	197.15	. . .	268.93	329.45	304.99
PBS4	307.85	291.18	299.94	. . .	217.38	205.57	200.11
PBS5	155.95	139.28	148.04	. . .	50.62	13.15	18.62

TABLE IV
RESULTS FOR THE ASSOCIATION MATRIX FOR STEP 3

Step 3	UE1	UE2	. . .	UE11	. . .	UE48	UE49	UE50
eNB	0	0	. . .	0	. . .	1	0	0
PBS1	1	1	. . .	0	. . .	0	0	0
PBS2	0	0	. . .	1	. . .	0	0	0
PBS5	0	0	. . .	0	. . .	0	1	1

TABLE V
ACTIVE PBSS AND ASSOCIATED UES FOR STEP 3

Base Station	Mode	Associated UEs
eNB	-	UE5, UE17, UE18, UE20÷UE40, UE46÷UE48
PBS1	Active-extended	UE1÷UE4, UE6÷UE10
PBS2	Active-extended	UE11÷UE16, UE19
PBS5	Active-extended	UE41÷UE45, UE49, UE50

TABLE VI
POWER BALANCE RESULTS FOR EACH STEP OF THE ALGORITHM

Step	ΔP_{uplink}	$\Delta P_{downlink}$	*PowerBalance*
1	-10.72%	7.61%	3.12%
2	-17.63%	15.50%	2.13%
3	**-22.74%**	**23.40%**	**0.66%**
4	-27.47%	31.30%	3.83%
5	-31.29%	39.34%	8.05%

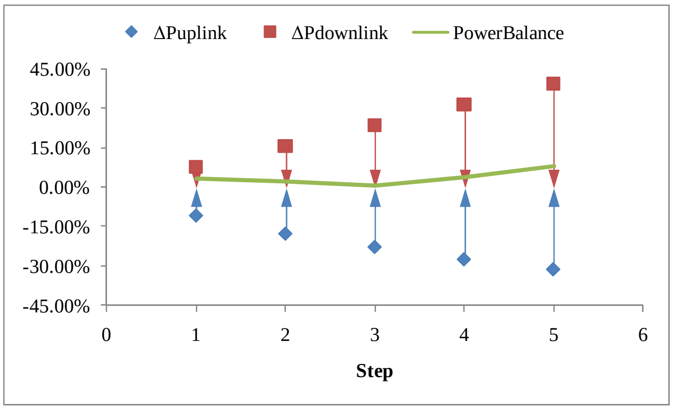

Fig. 2. Power Balance Results for each Step of the Algorithm

V. CONCLUSION

In this paper we propose an approach for finding an operation scenario of a LTE HetNEt cell with pico cells which has an optimum in relation to the energy efficiency of both the overall downlink power of the Base Stations (BS) and uplink power of the users in the cell. We introduced a parameter reflecting the changes in the downlink and uplink power in the cell when the pico base stations operate in different modes. The determination of an energy efficient operating solution from both base station and user point of view is based on an appropriate power model for the heterogeneous network and an add/drop heuristic procedure for putting into operation (activating) the pico base stations. The advantage of the proposed algorithm is that it is with low complexity as the number of calculations decreases with each step of the algorithm.

Future work in the aspect of this approach is related to the further development of the algorithm in order to reflect the dynamic changes in the user associations to the different pico base stations, i.e. mobility and activity of the users in the cell. A change of the user location or state will lead to change of the elements of the distance matrix and matrix of associations. Such cases must be analyzed and a proper solution must be proposed in order to avoid distortion of the power balance of the system and frequent and adverse changes of the operating conditions of the pico base stations. A throughput analysis together with the power efficiency is also foreseen.

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