Investigation on the Baseband Energy Saving in LTE

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Received 21 September 2014; Revised 14 November 2014; Accepted 26 November 2014

Abstract: The power models on base station and baseband in LTE are analyzed in the aspect of energy consumption firstly and then the novel baseband energy saving solution based on switching off baseband board, chip or module is proposed, which can decrease the power of the base station in LTE through adaptively adjusting the switch of the component according to the traffic load.

Key words: green communication, power model, baseband energy saving

1 Introduction

In the recent years, the wireless multimedia terminals have been widely used in the world, which leads to the high requirement of infrastructure for the mobile communication [1]. However, the ICT (Information and Communication Technology) sector in general and cellular network in particular has already consumed much energy in the earth [2]. Especially, the radio access part alone takes ups over 70% of the total energy consumption for many mobile carriers [3], [4]. Therefore, the energy-efficient design in wireless access network is an urgent task and is prompting new waves of research activities [5], [6].

In this paper, we briefly introduce the power consumption of base station and its baseband firstly. Secondly, we propose the novel solution on baseband energy saving, and then analyze the energy saving gain of this solution in theory, which is very useful for the academic research on green communication and can be referred by the scholars to investigate other energy saving schemes. Finally, we present the numerical results and conclude the paper.

2 Power model analysis

2.1 Base station

The base station (BS) consists of base band (BB), radio frequency (RF), power amplifier (PA), antenna, cooling part and supply, which is shown in Fig. 1 [7], [8]. At maximum load, the power consumption breakdown for different types of base stations is shown in [9]. It is interesting to note that in Macro BSs it is mainly the PA that dominates the total power consumption, owing to the high antenna interface losses. On the other hand, the breakdown is more balanced in micro BSs. Remarkably, in smaller BSs like Pico and Femto, it is the baseband part that dominates the overall power consumption. Therefore, it is important for the smaller base stations to reduce the power consumption of baseband. Meanwhile, the power consumption of Macro BSs and Micro BS drop off fast with the decrease of the traffic load, while the power of Pico and Femto change very little with the decrease of the traffic load.

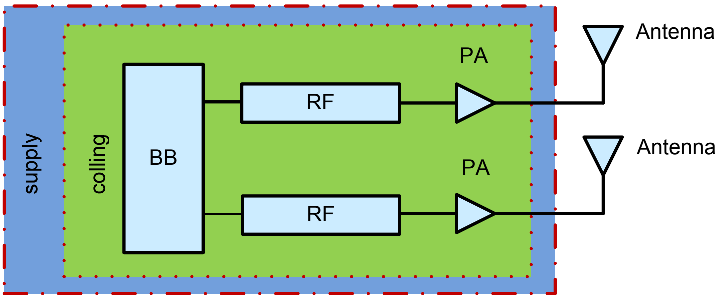

Fig. 1. Block diagram of a base station

As for the power consumption of the component in base station, it is clear that the power of PA increase with the traffic load, while the baseband processor shows a slight dependence on the traffic load due to the lower dynamic power consumption when less users/less subcarriers have to be processed. On the other hand, the small-signal RF transceiver shows no dependence from the traffic load. We make the deep research on the fact that the baseband power consumption changes very little with the increase of the traffic load, and find the reason may be that no component is powered off in the baseband even in the low traffic load. Thus, switching off the modules in the baseband is important for the baseband energy saving, especially in the low traffic load. Furthermore, it is very crucial to reduce the power consumption of baseband in the zero traffic loads.

2.2 Baseband

The baseband power consumption estimation assuming maximum load conditions and one antenna in the base station is shown in Table 1 [9]. The column ‘2010’ and ‘2012’ of the table are based on the component in 2010 and 2012 respectively. It is clearly seen that the baseband power consumption for macro was sharply dropped about 50 percents in two years, from 29.5 w in 2010 to 14.8 w in 2012. This value also dropped about 50 percents for micro, Pico and Femto between 2010 and 2012. According to the development of the components, the power of baseband will be further decreased.

Table 1. Baseband power consumption

	Base band power (W)		BB power/BS power	
	2010	2012	2010	2012
Macro	29.5	14.8	13%	9%
Micro	27.3	13.6	38%	29%
Pico	3.0	1.5	41%	33%
Femto	2.5	1.2	48%	39%

The baseband unit carriers out digital up/down conversion through performing digital signal processing. It includes filtering, modulation/demodulation, digital pre-distortion (only for large BS types), signal detection (synchronization, channel estimation, equalization, compensation of RF non-idealities), and channel coding/decoding. For large BSs the digital BB also includes the power consumed by the serial link to the backbone network. Finally, platform control and medium access control (MAC) operation add a further power consumer (control processor) [7], [8].

3 Baseband energy saving solution of switching off components

From the hardware view, the base station consists of multiple baseband boards and the baseband board includes multiple chips. Finally, each chip is composed of multiple modules or processors. The baseband board, chip and module in the chip are all called component. So, switching off the modules in the chip is the energy saving solution with controlling the smaller unit than switching off baseband board or chip.

Previously, we proposed the carrier optimization solution to implement switching off baseband board for the energy saving, and we can also switch off the chip to save the energy. In order to further decrease the power of baseband, we try to find the solution to switch off the modules in the chip. Generally speaking, there are two methods to use all these solutions for the energy saving when the traffic load decreases.

Method 1 – switching on the component gradually: when the new user accesses the network, the component with power on is firstly to be used, and the component with power off is switched on only when the components with power on are used up. The advantage of this method is to save the energy in the maximum limitation, while the disadvantage is affecting the accessing rate for the burst traffic when many uses come to this cell at the same time.

Method 2 – Switching on the component according to the scenario and time period: for example, the scenario can be divided into rural area, suburb and downtown. The time can be classified by busy period and spare period according to the traffic load. The number of components including baseband board, chip and the module in the chip in the each scenario and time period can be determined by the statistic information in history or self-training. In each case, we switch on the assigned number of components, and allocate the user in the components with power on averagely.

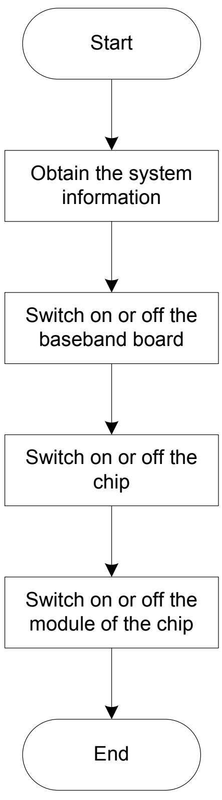

Fig. 2. Flowchart of energy saving solution with switching off the component

Based on above analysis, we propose the energy saving solution through switching off the components, which is implemented by four parts, shown in Fig. 2.

Part I: Obtaining the system information periodically. The information includes active subcarrier number in each baseband board, idle subcarrier number in each baseband board, user number in each subcarrier and traffic load. The time period to update the system information can be set by the operator.

Part II: Switching on or off the baseband board. Switch on the subcarrier and baseband board when the traffic load increases to the threshold. Hand over the user among the subcarriers, switch off the subcarrier without users, and then switch off the baseband board without active subcarriers when the traffic load decreases to the threshold.

Part III: Switch on or off the chip. Switch on the chip when the traffic load increases to the threshold. Hand over the user among chips and switch off the chip without users when the traffic load decreases to the threshold.

Part IV: Switch on or off the module of the chip. Switch on the module when the traffic load increases to the threshold. Hand over the user among the modules and switch off the module without the traffic when the traffic load decreases to the threshold.

Currently, the hardware supports to switch on or off the baseband board, chip and the module in the chip. We can control the time to switch on or off them through the calculation and determination of the software according to the change of the user number and traffic load.

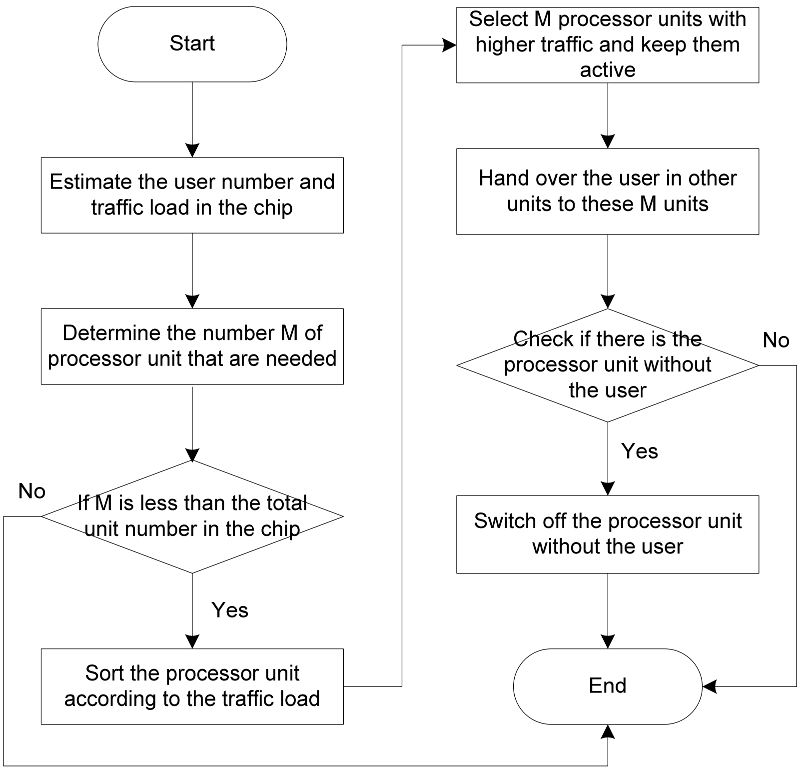

Fig. 3. Flowchart of switching on/off the module in the chip

Based on the solution of switching off the baseband board, we add the steps to switch off the chip and the module of the chip in order to achieve the better result of energy saving through controlling the smaller units. The principle to switch off the chip is the similar with that to switch off the module of the chip. In the following text, we take switching off the module as the example to explain this principle. In the chip, there are multiple parallel and independent modules, which are also called processing units. When there are a small number of users, some processing units are idle, so we can switch them off to decrease the energy consumption of the chip.

The module of the chip will be switched on or off according to the traffic load one by one. The flowchart is shown in Fig. 3 and the detail procedures are as follows.

Step 1: Do the statistic of the user number and traffic load in the chip

Step 2: Calculate the number of processor units that the current user and traffic load need, which is recorded as M. We should reserve the redundancy for the burst traffic in the calculation of this number M. For example, if the maximum number of the user that one processor unit can handle is X. Then we need 2 processor units when the user number exceeds 80% of X. Here, 80% is only for your reference and you can adjust it according to the startup speed of the chip and the maximum number that one chip can support. This example only intends to illustrate that we should reserve the redundancy during the estimation the number of the processor units that are needed, in order to assure the quality of the experience of the user who is accessing the network. Although the hardware technology is developed well and the startup speed is very fast, it still need the response time. So we should reserve the redundancy for it.

Step 3: Determine if M is less than the total number of the processor units in the chip. If yes, enter step 4, otherwise, enter step 9.

Step 4: Sort the parallel and independent processor units in the chip according to their user and traffic load.

Step 5: Select M processor units with more users or higher traffic than other units, and keep them in active.

Step 6: Hand over the users in other units to these M units, and allocate the traffic to one of the selected M processor units when new user comes. It is interesting to note that the energy consumption for the user handed over from one unit to another unit is almost zero. For example, three users are handed over from unit D to unit A. The energy consumption of this process is almost zero, which is far less than the energy that is saved by switching off the unit D. Furthermore, the energy consumption of unit A increases very little or just keeps unchanged with three more users, because the dynamic energy consumption of the baseband processor unit is very small.

Step 7: Check if there is the idle processor unit without the traffic outside the selected M processor units. If yes, enter step 8, otherwise, enter step 9.

Step 8: Switch off the processor unit without the traffic.

Step 9: End.

4 Analysis on the energy saving gain

The energy that can be saved through this solution is related to the power of baseband board, chip and the module in the chip, which are not same among the different manufacturers. Meanwhile, the power of base station is not same among the different manufacturers, which are their confidential information. However, when this solution is applied in the system from the different manufacturers, the common characters are as follows. (1) Switching off the baseband board can save the most energy, and switching off the chip can save more energy, and then switching the module in the chip can save the least energy. Therefore, during the implementation, we first switch off the baseband board, and then chip, the module in the chip, in order to save the energy in the maximum limitation. (2) Switching off one baseband board can save much energy while the energy consumption of the baseband grows very little after its traffic load increases because the dynamic energy of the baseband board is very little. It is in the same vein for the chip and the module of the chip. In the following text, we illustrate the energy saving gain of this solution by analyzing the relationship between baseband power consumption and base station power consumption.

The distributed base station has been applied widely in the world, which consists of base band unit (BBU) and radio remote unit (RRU). BBU include the BB processing part of Fig. 1, and RRU is composed of RF, PA and antennal of Fig. 1. The calculation of BS power is shown in the formula (1).

$$P_{BS} = \sum_{i=1}^{M} P_{BBU_i} + \sum_{j=1}^{N} P_{RRU_j} + P_{overhead} = \sum_{i=1}^{M} P_{BBU_i} + \sum_{j=1}^{N} \frac{P_{static}^{RRU_j} + \sum_{k=1}^{AN_j} \frac{P_{out_k}^{RRU_j}}{\alpha\left(P_{out_k}^{RRU_j}\right)}}{\eta_{DCDC}^{RRU_j}} + P_{overhead} \quad \textbf{(1)}$$

where M is the number of BBU, N is the number of RRU, P_{BBU_i} is the power of ith BBU, P_{RRU_j} is the power of jth RRU, $P_{overhead}$ is the additional power of the base station, such as cooling part, circuit loss and so on, AN_j is the antenna number of jth RRU, $P_{static}^{RRU_j}$ is the static power of jth RRU, $\eta_{DCDC}^{RRU_j}$ is the efficiency of direct current (DC) to DC in jth RRU, $P_{out_k}^{RRU_j}$ is the output power of the kth antenna in jth RRU, $\alpha\left(P_{out_k}^{RRU_j}\right)$ is the PA efficiency of kth antenna in jth RRU when its output power is $P_{out_k}^{RRU_j}$.

We assume the BS consists of one BBU and three RRU, and there are two antennas in each RRU, i.e. M=1, N=3, $AN_j = 2, j = 1,2,3$. In some traffic load, the power consumption data and efficiency are as follows.

$$P_{BBU_1} = 100 watt$$
$$P_{overhead} = 50 watt$$
$$P_{static}^{RRU_j} = 80 watt, j = 1,2,3$$
$$\eta_{DCDC}^{RRU_j} = 0.9, j = 1,2,3$$
$$P_{out_k}^{RRU_j} = 15 watt, j = 1,2,3; k = 1,2$$
$$\alpha\left(P_{out_k}^{RRU_j}\right) = 0.3, j = 1,2,3; k = 1,2$$

Then according to formula (1), we can get the BS power with the current traffic load.

$$P_{BS} = P_{BBU_1} + \sum_{j=1}^{3} \frac{P_{static}^{RRU_j} + \sum_{k=1}^{2} \frac{P_{out_k}^{RRU_j}}{\alpha\left(P_{out_k}^{RRU_j}\right)}}{\eta_{DCDC}^{RRU_j}} + P_{overhead} = 100 + \sum_{j=1}^{3} \frac{80 + \sum_{k=1}^{2} \frac{15}{0.3}}{0.9} + 50 = 750 watt \quad \textbf{(2)}$$

After using the energy saving solution proposed in this paper, the decrease proportion of BBU power is x in the same traffic load. After using the energy saving solution on the air-interface technology, the decrease proportion of antenna output power is y. And after using the energy saving solution on cooling, the decrease proportion of overhead power is z. Then the whole BS power can be calculated by formula (3).

$$P_{BS}^{New} = \sum_{i=1}^{M} \left(P_{BBU_i}(1-x)\right) + \sum_{j=1}^{N} \frac{P_{static}^{RRU_j} + \sum_{k=1}^{AN_j} \frac{P_{out_k}^{RRU_j}(1-y)}{\alpha\left(P_{out_k}^{RRU_j}(1-y)\right)}}{\eta_{DCDC}^{RRU_j}} + P_{overhead}(1-z) \quad \textbf{(3)}$$

Applying the value in formula (2) to formula (3), we can get

$$P_{BS}^{New} = 100(1-x) + \sum_{j=1}^{3} \frac{80 + \sum_{k=1}^{2} \frac{15(1-y)}{0.3}}{0.9} + 50(1-z) \\ = 100(1-x) + \frac{1000}{3}(1-y) + 50(1-z) + \frac{800}{3} \tag{4}$$

It is assumed in the formula (4) that PA efficiency does not change after the output power decreases with using the energy saving solution. Actually, the PA efficiency changes with the output power and each PA has its own PA efficiency curve. Considering the output power changes little, PA efficiency does not change much either. So we simplify the question with this assumption.

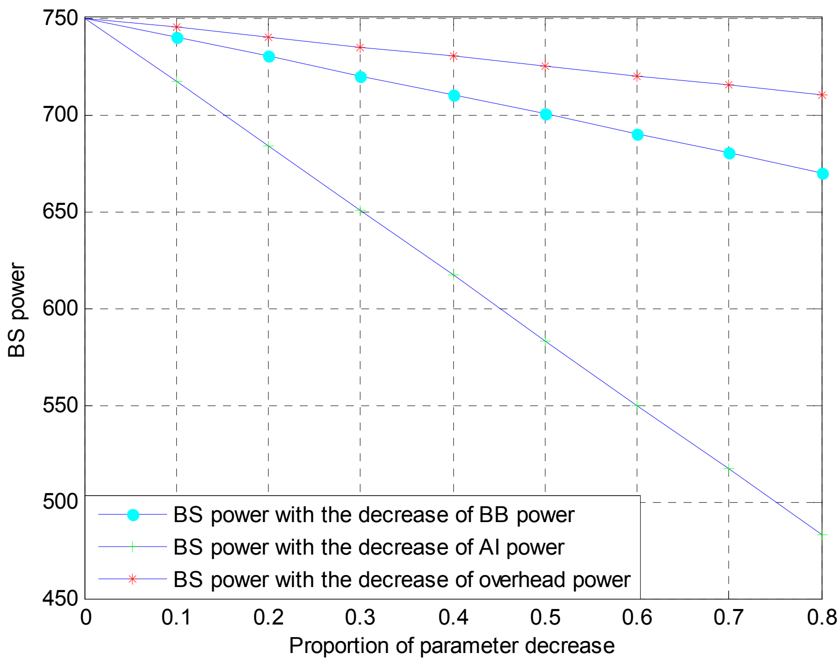

Fig. 4. The relationship between BS power and BB power, air interface power and overhead power

We can get the relationship between BS power and BB power, the output power of antenna (also called air interface power) and the power of other parts in BS (also called overhead power), which is shown in Fig. 4. It can be clearly seen from Fig. 4 that BS power decreases with the decrease of BB power, air interference (AI) power and overhead power. And the air interface power affects most on the BS power, which decreases about 166.67 watt when air interface decreases 50%. The BB power affects more on the BS power, which decreases around 50 watt when BB power decreases 50%. The overhead power affects least on the BS power, which decreases only 25 watt when overhead power decreases 50%.

The energy saving gain (ESG) of BS can be calculated in the formula (5)

$$EnergySavingGain = \frac{P_{BS} - P_{BS}^{New}}{P_{BS}} \tag{5}$$

Applying the value in formula (2) and (4) to formula (5), we can get

$$EnergySavingGain = 1 - \left[100(1-x) + \frac{1000}{3}(1-y) + 50(1-z) + \frac{800}{3} \right] / 750 \quad \textbf{(6)}$$

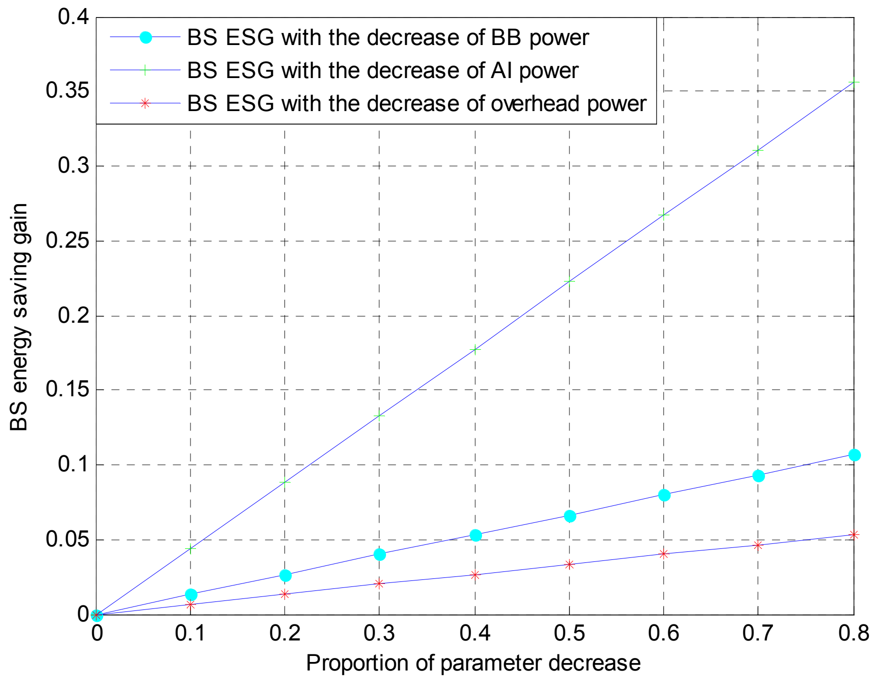

Fig. 5. Energy saving gain of BS

According to formula (6), we can get the relationship between energy saving gain of BS and the decrease proportion of BB power, AI power and the overhead power, which is shown in Fig. 5. It can be clearly seen from Fig. 5 that the energy saving gain of BS increases with the decrease of BB power, AI power and overhead power. And the air interface power affects most on the energy saving gain of BS, which is about 22.2% when air interface decreases 50%. The BB power affects more on the energy saving gain of BS, which is around 6.67% when BB power decreases 50%. The overhead power affects least on the energy saving gain of BS, which is only 3.33% when overhead power decreases 50%.

It can be seen from both Fig. 4 and Fig. 5 that except baseband power, AI power and overhead power are also important to decrease the BS power for the energy saving. Therefore, how to decrease AI power and overhead power is our future research direction.

In addition, the energy efficiency and spectrum efficiency are two important indexes of green communication system, where energy efficiency can be calculated by the system throughput in one unit of energy and the spectrum efficiency can be evaluated by the maximum transmission rate in one unit of spectrum. The energy saving solution proposed in this paper can increase the energy efficiency because the BS power decreases after the component is switched off but has little affection on spectrum efficiency.

5 Conclusion

In this paper, we propose the baseband energy saving solution with switching off the component, which optimizes switching off the baseband board, chip and the module of the chip jointly. In this solution, these components are switched on or off adaptively according to the traffic load with switching off the baseband board as the first priority and the module of the chip as the smallest unit. Meanwhile, the relationship between BS power and BB power, AI power and overhead power is analyzed in theory and the numerology result shows that the energy saving gain of BS is about 6.67% when BB power decreases 50%.

Acknowledgement

The work is supported in part by National Basic Research Program of China, 973 Program 2012CB316000, and National Major Project with No. 2015ZX03002006.

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