A Framework for Power Consumption Analysis of Green Cellular Networks with Separated Control and Data Base Stations

Yun Won Chung
School of Electronic Engineering, Soongsil University, Seoul, Korea
Email: ywchung@ssu.ac.kr

***Abstract*—In conventional green cellular network, network functionalities of Base Stations (BS) for network access and data service are tightly coupled. Although this joint control and data signaling approach is reasonable for homogeneous cellular networks, it is not appropriate for heterogeneous cellular networks with small cells overlaying macro cell, and a separated control and data signaling approach was proposed in the literature, where a macro cell is mainly responsible for control signaling to provide network access and a small cell is mainly responsible for data service. Although a detailed description of user equipment state transitions was provided previously, state transitions of a macro cell BS and a small cell BS have not been covered to the best of our knowledge. In this idea paper, we propose state transition diagrams for both the macro cell BS and the small cell BS, and present a framework for power consumption analysis of green cellular networks with separated control and data BSs.**

***Keywords*-power consumption, green cellular network, state transition diagram, base station**

I. INTRODUCTION

Recently, interest on green cellular networks has been increased and the basic idea of green cellular network is to turn off power consuming components of unnecessary Base Stations (BSs), especially during late night. To this end, numerous works on reducing power consumption of BSs of cellular networks have been carried out actively [1] [2]. In these works, it is generally assumed that network functionalities of BSs for network access and data service are tightly coupled and BSs manage both control signaling for network access and data signaling for data service.

Although the joint control and data signaling approach is reasonable for BSs in homogeneous cellular networks, it is not appropriate for heterogeneous cellular networks with small cells overlaying macro cell, since the joint approach is not efficient to deal with the issues such as high control overhead for growing traffic, lack of flexible topology adaptation accommodating traffic variations, and large control signaling overhead and frequent handovers [3]. To address these issues, a separated control and data signaling approach has been proposed in the literature [3][4]. In the separation approach, a macro cell is mainly responsible for control signaling to provide network access and a small cell is mainly responsible for data service. By separating network access and data service functionalities, a small cell BS can be put into sleep mode or turned off in order to reduce power consumption when there is few active mobile users under the coverage of a small cell BS, while idle mobile users under the coverage of a small cell BS can be served by a macro cell BS.

Xu et al. [3] separated network layer as control network layer and data network layer. The control network layer is responsible for supporting network access for mobile users and providing low rate data services. On the other hand, the data network layer is responsible for providing high rate data services. By doing this, transmission component of small cell BSs can be turned off if there is no requirement for high rate data service from any mobile users under the coverage of small cell BSs, and power saving can be achieved. In order to verify the support of the all the User Equipment (UE) activities in the separation approach, a state transition diagram for UE, which consists of detached, idle, c-active, and d-active states was proposed [3]. In c-active state, UE is served by control network layer and low rate data service is provided by a macro cell BS. In d-active state, UE is served by both control network layer and data network layer, and high rate data service is provided by a small cell BS.

Although a detailed description of UE state transitions was provided previously [3], state transitions of a macro cell BS and a small cell BS have not been covered to the best of our knowledge, which are essential for analyzing the power consumption of a macro cell BS and a small cell BS in the functionally separated cellular networks. In this idea paper, we propose state transition diagrams for both the macro cell BS and the small cell BS, and present a framework for power consumption analysis of green cellular networks with separated control and data BSs.

II. PROPOSED IDEA

In this idea paper, we define states for both the macro cell BS and the small cell BS, and propose state transition diagrams for the macro cell BS and the small cell BS. In each state of the state transition diagram, BS consumes different power and power consumption of a BS can be derived by calculating the weighted sum as follows:

$$P_{BS} = \sum_{i} Prob(i) \times P_i, \tag{1}$$

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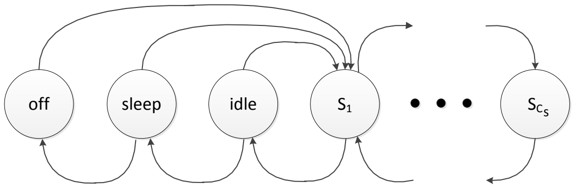

Figure 1. State transition diagram for a small cell BS.

where $Prob(i)$ denotes the steady state probability of state i and P_i denotes the power consumption of state i. Therefore, defining the state of a macro cell BS and a small cell BS and modelling the state transition diagram appropriately are essential to analyze the power consumption of the macro cell BS and the small cell BS.

Figure 1 shows a state transition diagram for a small cell BS which supports high rate data service from UE under the coverage of a small cell only area. In idle state, a small cell BS is ready for providing high rate data services to UEs and it moves to S_1 state after accepting high rate data service from a UE. If another high rate data service is accepted, the state moves to S_2, and similar transition occurs from S_{i-1} to S_i until i reaches to C_S, which is defined as the total number of data channels of a small cell BS. In idle state, if there is no high rate data service request from any UE until the expiration of idle timer, the state moves to sleep state and the small cell BS turns off some of components related with data transmission to save power. In idle state, if there is high rate data service request from UE, it moves to S_1 state. In sleep state, if there is high rate data service request from UE, it moves to S_1 state. Although a small cell BS firstly moves to idle state and stays there temporarily for the preparation of data service, and then moves to S_1 state in this case, we assume a direct transition from sleep state to S_1 state for simple analysis. In sleep state, if there is no high rate data service request until the expiration of sleep timer, the state moves to off state for more power saving. The transition from off state to S_1 state can occur if there is any high rate data service request, with the support of a macro cell BS, and the detailed algorithm of turning on the small cell BS in off state when a high rate data service is requested from UE is not covered in this idea paper since it is beyond the scope of this paper.

Figure 2 shows a state transition diagram for a macro cell BS which supports low rate data service from UE under the coverage of a macro cell and high rate data service from UE under the coverage of a macro cell only area. Total number of C_M channels are assumed in a macro cell BS, where it is assumed that one channel is required for a low rate data service and h channels are required for a high rate data service. Total number of L_M low rate data channels are reserved for low rate data service and total number of H_M high rate data channels are reserved for high rate data service, for simplicity. In the state transition diagram for a macro cell BS, there is no power saving state such as off and sleep state since the macro cell should support the network access for all the UEs under the coverage of a macro cell and thus awake all the time. In state(i,j) i denotes the number of low rate data service and j denotes the number of high rate data service; the following transitions occur depending on the events:

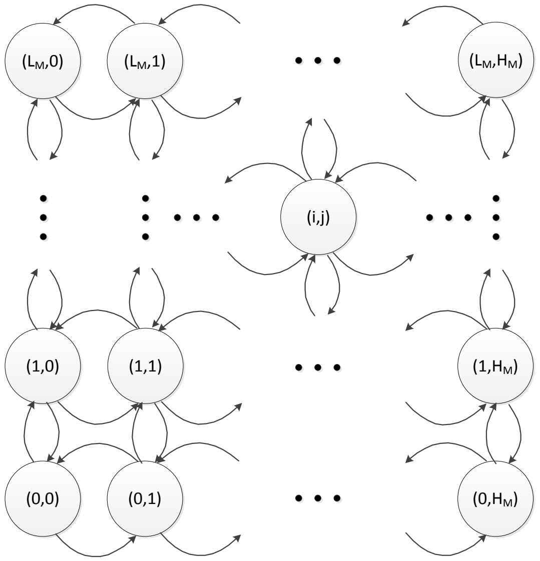

Figure 2. State transition diagram for a macro cell BS.

- (i,j) → (i+1,j): an arrival of low rate data service;
- (i,j) → (i-1,j): a departure of low rate data service;
- (i,j) → (i,j+1): an arrival of high rate data service;
- (i,j) → (i,j-1): a departure of high rate data service.

Since the power consumption of a BS consists of base power consumption (a) and traffic load proportional power consumption ($b\rho$), that is, $a + b\rho$ [1], we can obtain the power consumption of each state by calculating traffic load ρ using the channel occupied. For example, traffic load of state (i, j) for a macro cell BS can be defined as $\frac{i+hj}{C_M}$, where h denotes the number of required channels for a high rate data service. Then, the power consumption of the macro cell BS and the small cell BS is obtained as the weighted sum of power consumption of each state with the weight of the steady state probability of each state, as in eq. (1).

III. FUTURE PLAN

In our future work, we will derive the steady state probability of each state based on a detailed probability distributions of transition events between states which depend on mobility and traffic characteristics of UE, cell layout, call admission control scheme, etc. Power consumption of the macro cell BS and the small cell BS in the separation approach will be derived and compared with that of the joint approach. Then, an efficient power saving scheme will be drawn for a macro cell BS and a small cell BS, based on an interworking between them. Finally, an integrated power saving scheme which considers the power consumption of UEs as well as BSs will be proposed and analyzed.

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