

# Performance Modeling of Energy-Efficient Femtocell Base Stations

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**Abstract.** A lot of attentions have been paid to reduce energy consumption of mobile stations (MSs) since MSs operate with battery power. Recently, works on reducing energy consumption of base stations (BSs) also have been proposed since the energy consumption of BSs contributes to major parts of the whole network energy consumption, and the energy consumption of BSs is significantly higher than that of MSs. In this paper, we developed an analytical modeling for the performance analysis of the energy-efficient femtocell BSs, and analyzed the energy consumption and the number of additional handovers for varying parameter values. The analysis results will give an insight on the design and operation of energy-efficient femtocell BSs.

**Keywords:** femtocell; energy efficiency; power consumption; modeling; performance analysis

## 1. Introduction

A lot of attentions have been paid to reduce energy consumption of mobile stations (MSs) since MSs operate with battery power, and numerous works have been carried out [1]-[3]. In these works [1]-[3], the battery power of MSs can be saved by putting the MSs into low power consumption state, i.e., power saving mode or sleep mode, where MSs turn off their radio interfaces and only wake up periodically to check any incoming calls to them. These power saving mode and sleep mode are actually implemented successfully in many currently available wireless communication systems, such as wireless local area network (WLAN), 3GPP UMTS, and WiMAX.

Recently, works on reducing energy consumption of base stations (BSs) also have been proposed since the energy consumption of BSs contributes to major part of the whole network energy consumption [4], and the energy consumption of BSs is significantly higher than that of MSs. In [5]-[7], BSs are turned off when the traffic loads of the BSs are low and the traffic load of these BSs are taken care of by the neighboring active BSs by extending the radio coverage of neighboring BSs. In these works [5]-[7], sinusoidal traffic profile or traffic pattern of BSs during a day is used to efficiently turn off BSs when the traffic of BSs is low. In these works, however, it takes long time to turn on BSs from completely turned off state, which is not desirable for delay-sensitive applications. Also, it is not easy to control the extension of radio coverage of neighboring BSs for the backup of turned off BSs, if the layout of BSs is not regular due to the irregular shape of cells.

In [8], hierarchical cell layout consisting of femtocells and macrocell is assumed, as shown in Fig. 1 and the authors also try to reduce power consumption of femtocell BSs. The basic idea of reducing power consumption of femtocell BSs in [8] is similar to that of works in [5]-[7]. However, the authors in [8] do not completely turn off BSs for energy saving. Instead, they only turn off all pilot transmissions and the processing related with radio transmissions, and keep the connection between femtocell BSs and core network alive in order to avoid long boot-up delay times in [5]-[7].

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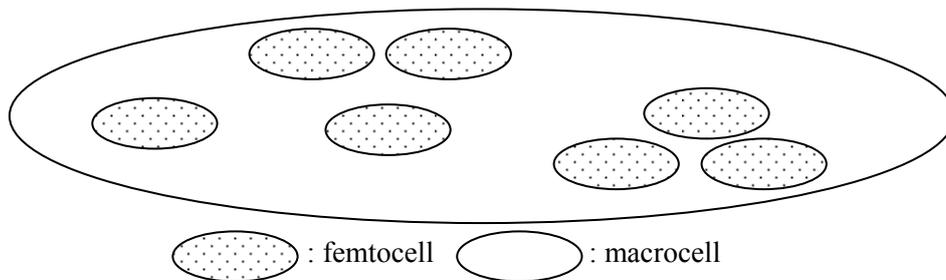


Fig. 1: Hierarchical cell layout of femtocells and macrocell.

In [8], the state of BSs where radio transmissions are turned off is called as *idle* state. On the other hand, the state where radio transmissions are turned on is called as *active* state. In [8], low-power sniffer capability is assumed in *idle* state in order to detect the activity of MSs from underlay macrocell. If the activity of an MS detected by the sniffer of a femtocell BS is higher than a threshold value, it is concluded that the MS is located within the coverage of the femtocell BS. Then, the BS reactivates the radio interface and its pilot transmission. After that, the MS sends the pilot information of the femtocell BS to macrocell when it is connected to the macrocell. Finally, the call is handed over from the macrocell to the femtocell, if the MS has access right to the femtocell.

Although the authors in [8] showed numerical results for power consumption reduction in femtocell BSs, it was carried out by simulation and thus, the analysis results in [8] cannot be extended easily to the analysis of other related works. Thus, we develop an analytical modeling for the performance analysis of the energy-efficient femtocell BSs in [8], in order to give a more insight on the performance analysis and to provide a more tractable analytical tool. Also, the number of additional handovers in [8] is analysed for varying parameter values. Therefore, the main contribution of this paper is development of an analytical methodology for the performance analysis of energy-efficient femtocell BSs considering handovers between femtocells and macrocell.

The remainder of this paper is organized as follows: In Section 2, the performance of energy-efficient femtocell BSs is modelled mathematically. Then, numerical examples are presented in Section 3 to provide performance analysis results. Conclusion and future work are given in Section 4.

## 2. Analytical Modeling

In this paper, we basically assume the same network architecture as in [8], which consists of femtocells and underlay macrocell. BSs turn off all pilot transmissions and the processing related with radio transmissions, and keep the connection between femtocell BSs and core network alive. In this section, we firstly classify processing related with outgoing call based on the state of femtocell BSs and the location of MSs, as in Table I. As shown in Table I, state transition and handover are only needed when an MS is located within femtocell and a BS is in *idle* state. Thus, we need to derive the probability of such case to derive the number of additional handovers. Also, the energy consumption of a BS can be obtained by deriving the probability of states of a BS.

Table 1: Processing related with outgoing call

		State of a BS	
		<i>Active</i>	<i>Idle</i>
Location of an MS	Femtocell	No state transition No handover	Transition to <i>Active</i> State Handover
	Macrocell	No state transition No handover	No state transition No handover

For analytical modeling, the followings are assumed:

- The shape of femtocell and macrocell is assumed as circle. The radius of femtocell is  $r$  and the radius of macrocell is  $R$ . Thus,  $N_{\max} = (R/r)^2$  cells are needed to cover macrocell coverage by femtocells, by assuming exclusive layout of femtocells.
- It is assumed that  $n$  ( $1 \leq n \leq N_{\max}$ ) femtocells are deployed within a macrocell.
- Call arrivals to a macrocell occur according to a Poisson distribution with parameter  $\lambda_{\text{macro}}$ .
- Call holding time follows an exponential distribution with mean  $1/\mu_c$ .
- MSs are uniformly distributed within a macrocell.
- The *active* state of a BS is modeled as  $M/M/\infty$  queueing model [9].
- The power consumptions in *active* state and *idle* state are denoted as  $P_{\text{active}}$  and  $P_{\text{idle}}$ , respectively. The power of  $P_{\text{sniff}}$  is also additionally consumed in *idle* state.

Based on the above assumptions, the probability that an MS is located within a femtocell,  $\text{Pr}(\text{femto})$ , is obtained based on uniform distribution of MSs as follows:

$$\text{Pr}(\text{femto}) = n/N_{\max}. \quad (1)$$

Also, call arrival rate to a femtocell is calculated as follows:

$$\lambda_c = \lambda_{\text{macro}}/N_{\max}. \quad (2)$$

The probability that a BS is in *active* state is derived as follows:

$$\text{Pr}(\text{active}) = 1 - e^{-\rho_c}. \quad (3)$$

where  $\rho_c = \lambda_c/\mu_c$ , by using Markov chain analysis [9].

Then, the probability that a BS is in *idle* state is given as follows:

$$\text{Pr}(\text{idle}) = 1 - \text{Pr}(\text{active}) = e^{-\rho_c}. \quad (4)$$

Using these results, energy consumptions in conventional scheme with no power saving during one hour,  $E_{\text{conventional}}$ , and energy consumptions in the enhanced scheme proposed in [8] during one hour,  $E_{\text{enhanced}}$ , are obtained as follows:

$$E_{\text{conventional}} = P_{\text{active}} * 3600 \text{ (J)}, \quad (5)$$

$$\begin{aligned} E_{\text{enhanced}} &= (P_{\text{active}} * \text{Pr}(\text{active}) + (P_{\text{idle}} + P_{\text{sniff}}) * \text{Pr}(\text{idle})) * 3600 \text{ (J)} \\ &= (P_{\text{active}} * (1 - e^{-\rho_c}) + (P_{\text{idle}} + P_{\text{sniff}}) * e^{-\rho_c}) * 3600 \text{ (J)} \end{aligned} \quad (6)$$

Also, the number of additional handovers from macrocell to femtocell during one hour within a femtocell is obtained as follows:

$$\text{NH} = \lambda_c * \text{Pr}(\text{femto}) * \text{Pr}(\text{idle}) = \lambda_c * n/N_{\max} * e^{-\rho_c} \quad (7)$$

### 3. Numerical Examples

In this section, numerical examples are presented to provide performance analysis results based on Eqns. (1)-(7). Figure 2 shows the energy consumption in Eqns. (5) and (6) for varying the traffic load  $\rho_c$  for  $P_{\text{active}}=10.2\text{(W)}$ ,  $P_{\text{idle}} = 6\text{(W)}$ ,  $P_{\text{sniff}}= 0.3\text{(W)}$ , and  $1/\mu_c=1/20\text{(h)}$ . As shown in Fig. 2, the energy consumption of the proposed scheme is less than that of the conventional scheme. Also, it increases as traffic load increases for large values of traffic load, while there is little increase for small values of traffic load. Based on Fig. 2, it is concluded that the enhanced scheme proposed in [8] has more benefit when traffic load is low.

Figure 3 shows the number of additional handovers in Eqn. (7) for varying the traffic load  $\rho_c$  for  $n=50$ ,  $R=2\text{(km)}$ ,  $r=0.2\text{(km)}$ , and  $1/\mu_c=1/20\text{(h)}$  with  $\lambda_{\text{macro}}=20, 200, \text{ and } 2000\text{(h)}$ . As shown in Fig. 2, the number of handovers decreases as traffic load increases, since large value of traffic load corresponds to less probability of idle state. Also, the number of handovers increases as  $\lambda_{\text{macro}}$  increases.

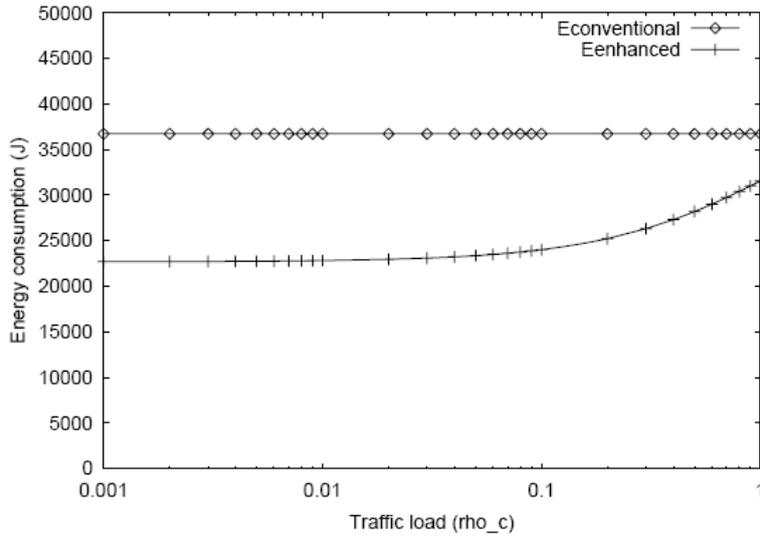


Fig. 2: Energy consumption for varying traffic load  $\rho_c$ .

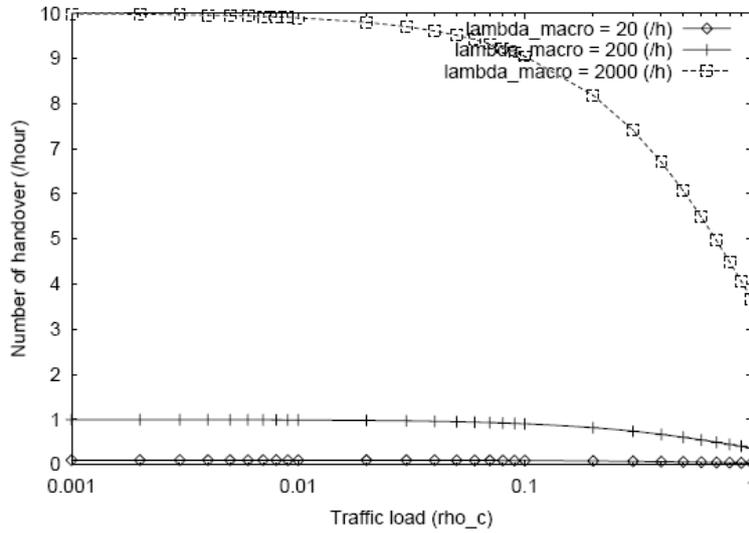


Fig. 3: Number of additional handover for varying traffic load  $\rho_c$ .

## 4. Conclusion and Future Work

In this paper, we developed an analytical modeling of the energy-efficient femtocell BSs and analyzed the energy consumption and the number of additional handovers for varying parameter values. These results and analytical methodology can be extended to a more complete modeling and analysis based on more realistic assumptions, which is left as our future work. We hope that our future work can give a much insight on the design and operation of energy-efficient femtocell BSs.

## 5. Acknowledgements

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