Energy-Efficient Base Station Operation in Heterogeneous Cellular Networks

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Abstract

Heterogeneous cellular networks can provide high throughput and coverage compare to conventional networks of only macrocell deployment, however it operates regardless of total power consumption, which is a very important issue of modern cellular networks. We propose a policy that control the on/off state of base stations in heterogeneous networks according daily traffic profile. Under this policy, the total power consumed can be significantly reduced when the traffic is low while preserving QoS requirement.

1. Introduction

Nowadays, energy-efficiency issue in design of wireless cellular networks has become very important aspect beside improving the total throughput of the system. This is because of the huge amount of energy consumed and CO_2 emissions caused by the operation of the networks. It is reported that the Information and Communication Technology industry takes 2% and 3% of global CO_2 emissions and energy consumption respectively [1], in particular, nearly 60% of this belongs to users and devices in mobile networks.

Heterogeneous networks consists of macrocell and micro/picocells which cover dense traffic or cell edge areas is well known that it improves not only network capacity and coverage but also energy-efficiency such as improvement in term of the total throughput over the total power consumption [2] [3]. However these works do not consider the dynamic on/off operation of the system according to real traffic pattern. Since the real traffic patterns are highly periodical and the duration of low traffic (10% of peak traffic) is quite significant [4]. On the other hand, base station (BS) which is accounted for nearly 60% of the total power consumption of cellular networks. Base on these, in this paper, we propose a scheme that turning on/off the radio resources of macro BS and pico BSs in picocell-deployed heterogeneous cellular networks to reduce the total power consumption of the systems according to the traffic pattern while preserving QoS requirements.

2. System model

In this paper, we consider a two-tier heterogeneous networks, the first tier is macrocell equipped with R radio resources such as the number of transmitters for GSM, carriers for 3G, HSDPA or LTE, and have N picocells forming the second tier within macrocell coverage area (Fig. 1). Users within the coverage area of picocells can communicate with both macro and pico BS, we assume in this case they will automatically connected to picocell due to short distance to pico BS. When users leave picocell, on going calls of users will be transfered to macro BS via handover. Let's consider the scenario in Fig. 1, traffic in picocell 1 is decreasing, traffic in macro and picocell 2 are increasing, the macro BS knows about traffic information of system and will decide: If the traffic in picocell 1 decreases to a certain level that macro BS can handle the traffic with acceptable users perceived QoS, it is beneficial to turn off picocell 1 to save energy, in this case, ongoing calls of users in picocell 1 will be handover to macrocell. If the macro BS can serve the

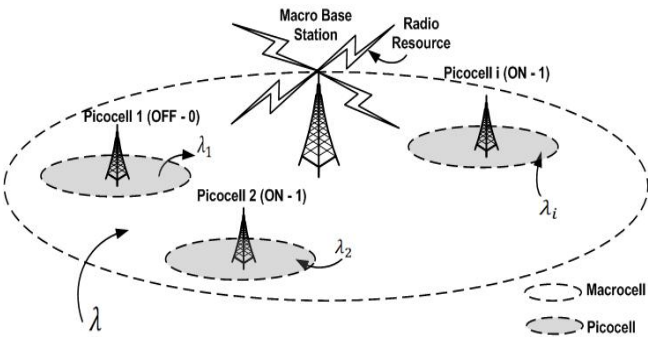

Figure 1. Macrocell with overlaid picocells

handover traffic from picocell 1 but has to activate additional radio resources to serve the handoff traffic which in turn causes more power require or the QoS is degraded, then clearly doing nothing is the optimal action.

The power consumption of macro BS is given by [5]

$$P_m = P_{cst} + \sum_{j=1}^{R}(P_{trx} + \rho_j P_{\max}/\omega), \qquad (1)$$

where P_{cst} is the power consumed due to transport and processing units, P_{trx} is the fixed power of the transceiver and $P_{\max}$ is the maximum output signal of the power amplifier, ω is the direct current to radio frequency conversion factor, ρ_j is the utilization (load) of radio resource j. We assume that each picocell is equipped with one radio resource and the energy consumption is given by [4]

$$P_p = \rho P_{dynamic} + P_{fixed}. \qquad (2)$$

Similar to macro BS, P_{fixed} here is the fixed power consumption and $P_{dynamic}$ is the power consumption that proportionally with the utilization (load) of picocell, $P_{fixed} + P_{dynamic} = P_{p,\max}$ where $P_{p,\max}$ is the maximum power consumption of picocell (when operate in full load).

We consider time is divided into equal periods in which the traffic is consider as constant. At period t^{th}, system state is denoted as $s_t = (r_t, l_{t,1}, l_{t,2}, \ldots, l_{t,N}) \subset S$, where S is the state space, r_t is the number of active radio resources and $l_{t,(.)}$ represents the state of picocells, i.e. $l_{t,i} = 1$ if picocell i^{th} is activated and $l_{t,i} = 0$ if picocell i^{th} is deactivated. The control variable is defined as $a_t = (m_t, p_{t,1}, p_{t,2}, p_{t,3}, \ldots, p_{t,N}) \subset A$, where A is the action space, m_t and $p_{t,(.)}$ are actions corresponding to radio resources of macrocell and picocells respectively, i.e. $m_t = -1, 0, +1$ and $p_{t,i} = 1$ if $l_{t,i} = 0$ and $p_{t,i} = 0$ if $l_{t,i} = 1$. We define the cost per stage $C_t(s_t)$ in period t^{th} is the power consumption of the system in state s_t knowing the distribution of traffic, i.e. $C_t(s_t, a_t) = P_m(s_t) + P_p(s_t)$, $P_p(s_t) = \sum_{i=1}^{N} l_{t,i} P_{p,i}$, $P_m(s_t)$ is given by (1), replacing R by r_t, $P_p(s_t)$ is given by (2). Our aim is to find the actions that minimize the total power consumption of the system over a period T and satisfy QoS requirement, i.e.

$$\min_{a_t} \sum_{t=0}^{T} C_t(s_t, a_t)$$

s.t. QoS requirements.

This is a dynamic programming problem over a finite horizon with finite, discrete state and action space, we propose an algorithm base on *backward induction algorithm* in [6] to solve this problem with a little modification taking the QoS requirement into account as follow

Step 1: Initiating the termination cost $J_T(s_T)$.
Set $t = T - 1$.
Step 2: For all $s_t \subset S$, $a_t \subset A$ calculate:
2a: $J_t(s_t) = \min_{a_t}\{C_t(s_t, a_t) + J_{t+1}(s_{t+1})\}$.
Set $a_t^* = \arg min\{C_t(s_t, a_t) + J_{t+1}(s_{t+1})\}$.
2b: Calculating the corresponding QoS.
2c: If QoS meet requirement
then go to step 3. Else
Set $A = A \setminus \{a_t^*\}$ and return 2a.
Step 3: If $t > 0$, decrement t and return to step 1.
Else stop.

3. Conclusion

In this paper, we consider the dynamic on/off operation of two-tier heterogeneous networks. Based on dynamic programming framework, we propose a scheme that base on traffic information, the macro BS will choose whether activate or deactivate radio resources of macro BS and pico BSs that resulting in the minimum total power consumption while satisfy the QoS requirement.

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