Power-consumption minimization mechanism for heterogeneous multi-cell cellular network

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Abstract

With growing concern of global warming, decreasing of CO2 emission is a major issue in many area of industry. With the fact that Information and Communication Technology consumes large amount of energy, reduction of energy consumption in ICT attracts attention of research community. We propose a power consumption minimization technique in the cellular network composed of various capacities of base stations. Meanwhile, user service quality should remain uninfluenced with power consumption minimization mechanism. The problem is similar to 'Set Cover' problem, which is famous NP-complete problem. Heuristics and simulation result to show the efficiency of proposed algorithm will be shown.

I. Introduction

Many works point out that global warming is a major concern of modern world. The energy consumption is expected to increase more rapidly with current trends of energy use [1]. According to [2], Information and Communication Technology (ICT) causes about 2% of total CO2 emission of the world. Various causes of CO2 emission in this area have been studied, and among many causes that cause energy consumption in the communication network, base station plays a major role of power consumption in wireless communication network [7]. In this paper, we propose a base station control mechanism for green network, in which a macrocell or femtocell base station can be turned on and off dynamically according to user demand for traffic in a coverage area of the base station. Firstly the motivation will be given, and network model follows. Problem definition, a heuristic method to solve the problem and simulation result will be described.

II. Motivation

A femtocell base station is low-power, low-cost cellular base station targeted on coverage expanding and capacity enhancement of cellular network [2]. A femtocell base station is connected to broadband internet access network, and communicates with cellular network service provider to connect the user to the cellular network. Typical deployment scenario of a femtocell base station is that if a user wants to enhance the cellular capacity in his home, he purchases a femtocell base station from the market and installs it in his home, and then connects the base station to the broadband access in his home. With increasing demand of high quality data service using cellular phone, it is expected that lots of femtocell base stations will be deployed in the future [5].

In a deployment scenario above, a user does not consider anything about macrocell and other femtocell base stations. If the objective of a femtocell base station is, in particular, enhance capacity of cellular network in the house, the coverage of a femtocell base station will be overlapped to that of macrocell base station, as well as other femtocell base stations installed by other users in the vicinity.

In the terms of power consumption, a base station serves no user need not to be turned on. In particular, if other overlapped femtocell base station, say fBS1, can serve the user attached to a femtocell base station, say fBS2, and then fBS2 can be turned off while fBS1 provides all needed service to the users. Moreover, if user connectivity can be covered with several femtocell base stations in a certain area, then a macrocell base station covers the area need not use its full capacity and is enough to send membership management beacon regularly.

III. Network model and Problem Definition

We propose a simple model for the network. In our model, a base station i is characterized into three parameters, power consumption p_i, number of available connection c_i, and transmission range t_i. A user j has a vector of signal strength from each of base stations, $s_j = (s^1_j, s^2_j \dots s^n_j)$. An element s^i_j , which is signal strength of base station i experienced by user j will be 0 if user j is out of the transmission range of base station i. We did not differentiate the macro- and femto- base stations other than transmission range and power consumption, because there is no explicit difference other than those two factors in terms of power consumption related to our problem. The capacity difference between two types of base station is represented by the number of available connection parameter.

With this model, we can define power minimization problem like following:

POWER-MINIMIZATION: With given a set of users and a set of base stations, find a set of turned-on base stations to provide network coverage all users.

On a model described above, we do not consider the capacity of the femtocell base station in the terms of available bandwidth, or the traffic requirement of the user. With the model like this, the problem is a variant of Set Cover problem, which is a famous NP-complete problem. The set cover problem is with given a set U of sets U_i, to find a minimal subset U_s of U such that elements in $U_u = \Sigma U_j \in U_s$ covers all elements in the ΣU_i. Among the variances of the Set Cover problem, 'Weighted-Minimal Set Cover problem' is similar to our POWER-MINIMIZATION problem. In the next section, we describe the Weighted Minimal-Set cover problem and a heuristic for the problem.

IV. Weighted Minimal Set Cover problem

Firstly we describe Minimal Set Cover problem, which is a special case of Weighted Minimal Set Cover problem. The problem is defined as following [4]:

MINUMUM-COVER: With given a Collection C of subsets of a finite set S and a positive integer $K \leq | C |$, Does C contain a cover for S of size K or less?

And if we modify the problem by weighting each element C_i of the collection C, then we can obtain the weighted version of Minimal Set Cover problem, Weighted Minimal Set Cover Problem.

WEIGHTED-MINUMUM-COVER: With given a Collection C of subsets of a finite set S and a positive integer K and a set of positive integers $v = \{v_1, v_2, \dots, v_n\}$ such that $| V | = | C |$ and v_i weighs each element $C_i \in C$, Does C contain a cover for S of size K or less?

MINIMUM-COVER problem is a special case of this problem; with all weight v_i equals 1. Like Set Cover problem, MINIMUM-COVER and WEIGHT-MINUMUM-COVER are also NP-complete problem, so we do not have any polynomial time solution for the problems. For our POWER-MINIZATION problem, a user set covered by a single base station will be represented by an element c of collection C, and power consumption for each base station will be a weight allocated to c. Indeed we need to find minimal K, and it can be obtained by not-so-many simple tries using the heuristic. Here we propose a simple heuristic for our problem:

Heuristic:
Input : a set of users, a set of base stations
Output : a set of turned-on base station

1) Sort the base stations, with ascending order in terms of the power consumption. Let's assume that the base station with minimal power consumption is numbered as 1, and the second one is 2, and so on.
2) Select base station 1, and mark the users as 'covered by base station 1' covered by the base station. The number of users covered by this base station should be less than c_1, and if there are more user than the capacity of the base station, then select the users with most received signal strength. Mark the users can be covered but are not covered as 'potentially covered by base station 1'. Remove the base station number 1 from the set. Mark the base station as 'turned on'
3) After step 2, select next-minimal power consuming base station. Do the same covering process as step 2 with uncovered (including potentially covered) users.
4) While repeat step 3, do the optimization process. The optimization process is removal of unnecessary

base station. If users covered by a single base station can be covered by other two or more base stations within the capacity limit of each base station, then modify the marking on those users as covered by each base station and mark the original base station as turned off.

V. Simulation

We evaluated the energy saving effect based on our heuristics. In our simulation, transmission range, power consumption, capacity of each base station and the physical position, represented by (x, y) pair, is explicitly given for users and base stations. A set of user is given and received signal strength which is experienced by each user is determined by the distance. We did not consider the interference or fading effect.

We limited number of users less than 100, because if the load on the network is above a certain level, then we cannot turn off any of base stations, so that there is no room for additional energy saving. In our simulation, we have one hexagonal cell which is covered by three 3-sector macrocell base stations, and 400 femtocell base stations on the field. Typically a macrocell base station consumes a few hundred watts, and a femtocell base station consumes more than ten watts. In our simulation, a macrocell base station consumes 600W and its coverage radius is 600m, and a femtocell base station consumes 12W and it covers 30m radius area. We ran 500 times of simulation.

Without optimization, we should turn on all base stations, so total power consumption will be 600x3 + 12x400 = 6600W, but with optimization, on average, nearly 1700W is sufficient to cover all the users. We have about 75% of energy saving using our optimizations. The result shows powerful energy saving effect of our algorithm, but we point out that the low load on the network enable the high saving ratio. Also if we consider capacity of femtocells and user traffic requirements, then number of femtocell base stations that can be turned off will be far more decreased. We will leave this as our future work.

VI. Power consumption model

There is a related study about power saving using base station control [3] which insists that 'floor level' of power consumption of a base station plays a major role in the total power consumption of a base station. Our work also based on the same basis, so we do not consider transmission power control for each base station, or turning off one or more of transceivers of a base station site which contains more than one 3-sector antenna set.

On the other hand, radio equipment of base station takes major part in power consumption of the base station [6]. So we consider dynamical transmitter/receiver on/off control to save more power of a base station site, but first, detailed power model of a base station and base station site is needed to be studied.

VII. Conclusion and Future work

In this paper, we studied a communication network architecture that minimizes total power consumption of the network using optimization mechanism by turning off unnecessary base stations according to user distribution. Simulation shows about 75% of energy saving compared to non-optimization model, but for our future work, firstly we will study a complicated model that each base station has its own capacity and each user has own requirement for QoS. Also we need to consider the user traffic model, in the way how the user connects and uses the wireless resources in typical wireless communication networks.

Acknowledgements

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